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Smithsonian August/September 1991

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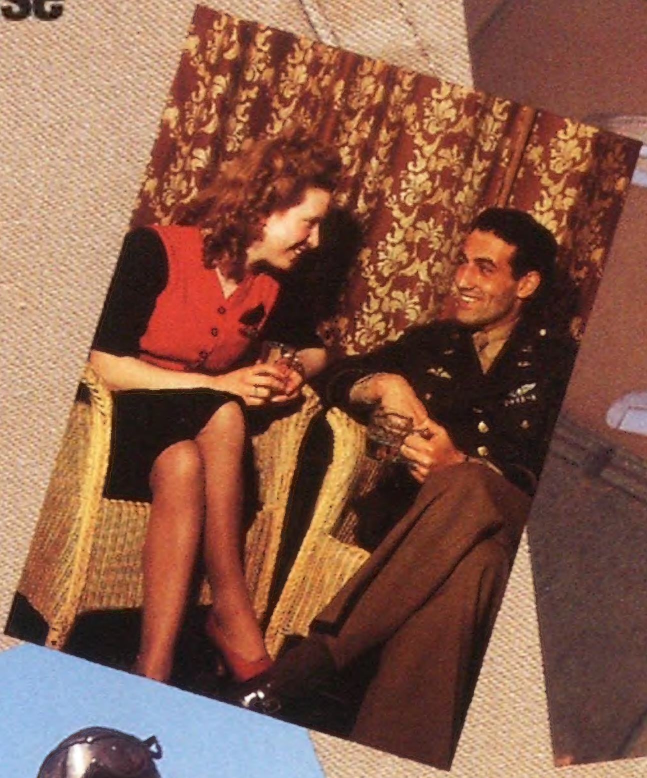

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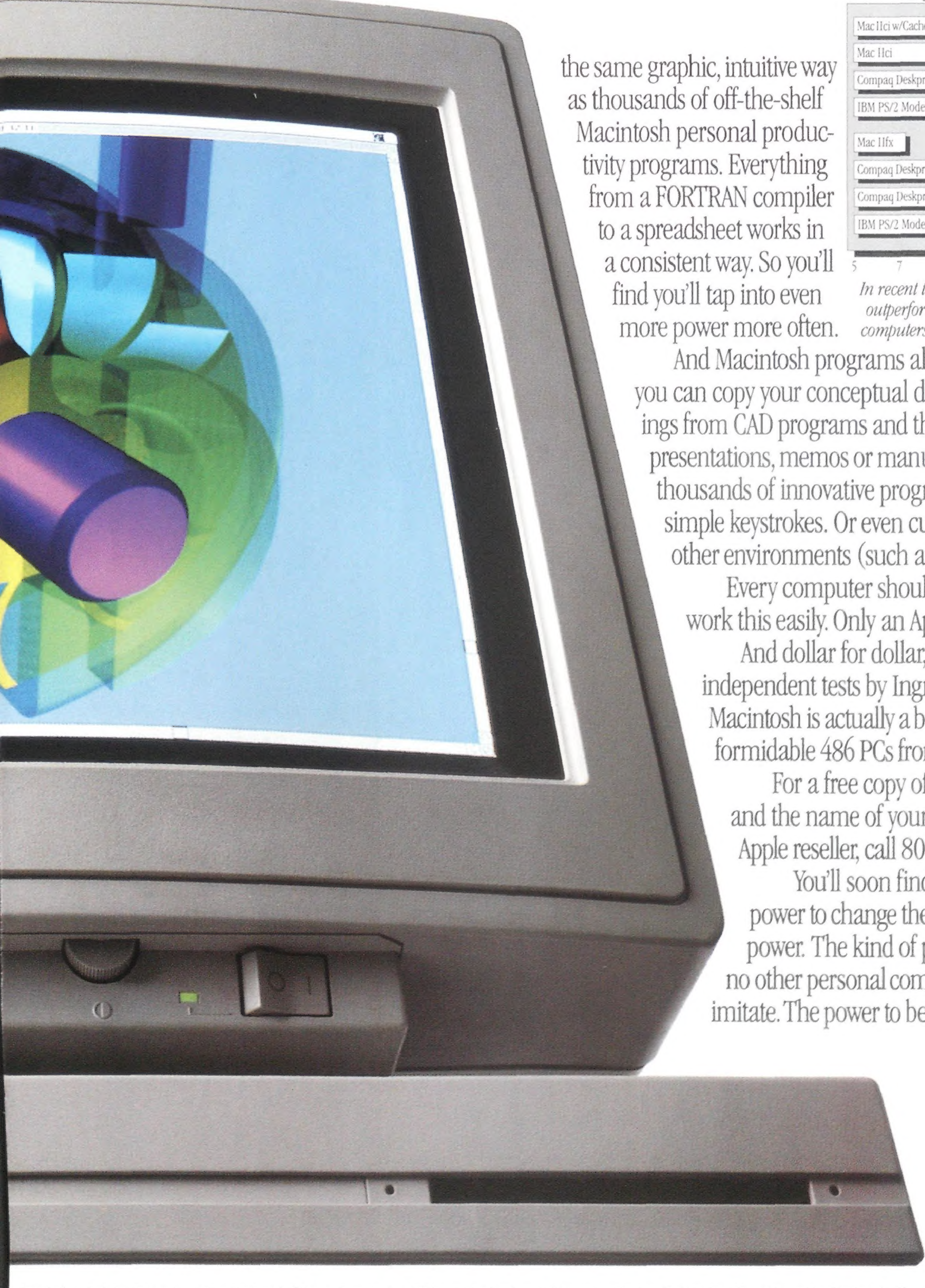

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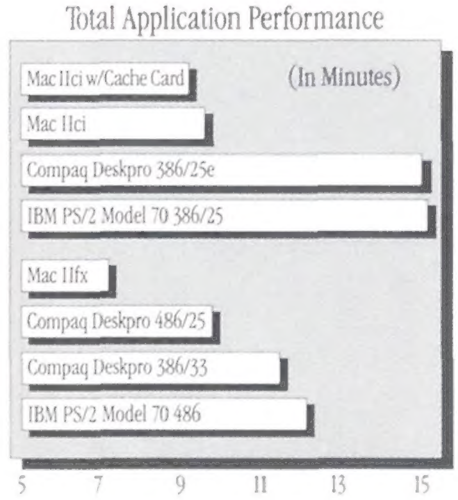

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August/September 1991
Volume 6, Number 3

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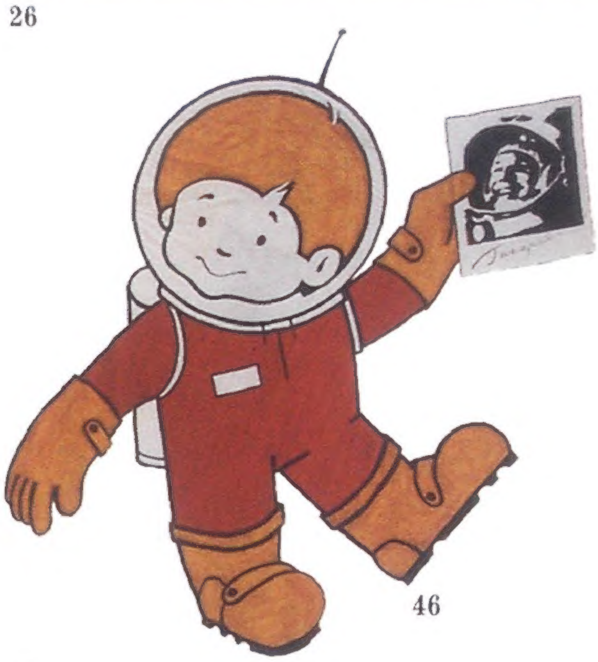

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Cover: A scrapbook of World War II photos documents the days when both color film and the soldiers using it were young.

Departments

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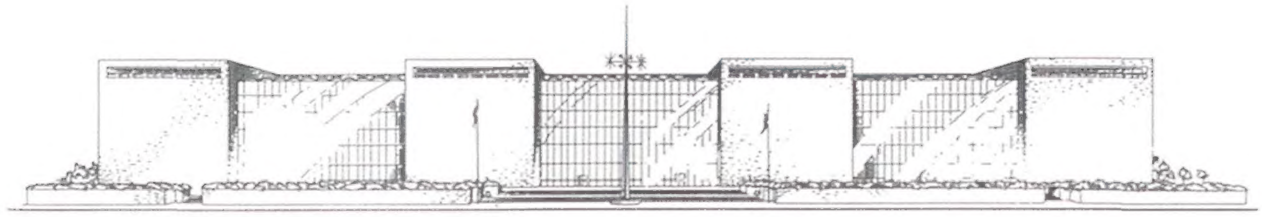

Approachable Role Models

From time to time I am visited by serious citizens proposing a novel approach to achieving national science literacy. They hand me an attractive brochure with a compelling title, like *Onward USA!*, tell me that a number of congressmen are already behind their approach, and ask that the National Air and Space Museum join their crusade.

What is this science literacy that has suddenly become a national priority? Is it the training of more young scientists who will recapture the lead in research that Americans held for many decades? Or is the emphasis to be on science education for every school child, coast to coast? Or can we do both with a single all-encompassing program?

I'd like to think that we can do both, with two quite different aims: to teach every child to think clearly, and to persuade some youngsters to become scientists or engineers.

The United States has always been a country where education for all children is a high priority. What should our goals be in such an approach?

One way to answer that question is to ask about the level of science comprehension we would recommend for the general citizen. Could we expect an ability to understand science well enough to formulate sound judgments on the merits of a particular piece of scientific or medical work under debate in the newspapers? Probably not; science has become extremely complex, and often a sound judgment is difficult even for the expert. We see that in the range of scientific predictions we read on the imminence of a catastrophic atmospheric greenhouse effect.

But if science is too complex for the average citizen to formulate clear judgments on questions of social importance, does that mean we should lower our educational aims even further?

Rather than pursuing this line of inquiry, I believe a far more useful approach would be to ask: What could our schools teach children in order to better prepare them for life in our increasingly complex scientific/industrial society?

We take it for granted that the modern citizen knows how to drive a car, that a minimum of mathematical skill is required to fill out an income tax return, that even the simplest jobs may require a skill equivalent to operating a cash register at a supermarket, that one may need to handle the increasingly demanding touchtone telephone that instructs us on a series of alternatives we can select from when we place a call for information and have the misfortune of reaching a machine.

All of that takes logical thought and self-confidence in solving problems. Scientists make use of both traits and could help youngsters learn them.

Do hands-on experiments for schoolchildren help to instill these qualities? I'm not sure. With a skilled teacher, the simplest devices can demonstrate fundamental principles; a poor teacher sends a child daydreaming in seconds.

Turning to the question of how to attract youngsters to become scientists, the answers are much clearer. Over the years, interviews conducted with leading scientists have, time after time, shown that inspiration to go into science as a career came from a caring teacher, parent, or other accessible role model. I emphasize *accessible* because I do not believe we can substitute televised class presentations for the kind of inspiration a live teacher can offer. Youngsters need a person with whom to talk and share innermost thoughts. Often that can only be a teacher.

If we had to select one way of investing our money in science education, it should probably be in better resources for our schools, so we could attract the best natural teachers with better salaries, working conditions, and teaching equipment.

That's probably the best investment we can make in the nation's future right now.

—Martin Harwit is the director of the National Air and Space Museum.

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Letters

Mustang Memories

I found "Meet the Mustang" (June/July 1991) extraordinary. Maybe it was Ron Dick's exhilarating second-person style or just the right combination of technical detail, flight manual fragments, and readability for non-pilots like myself. Can you put Dick into more cockpits—with pen and paper, of course?

John T. Petrie
Mt. Airy, Maryland

Forty-five years ago, I met my first Mustang with the same sense of privilege, joy, thrill, and apprehension that Ron Dick described in his insightful and accurate report of his first flight in that great old "pursuit" plane.

Robert G. Bjoring
Menlo Park, California

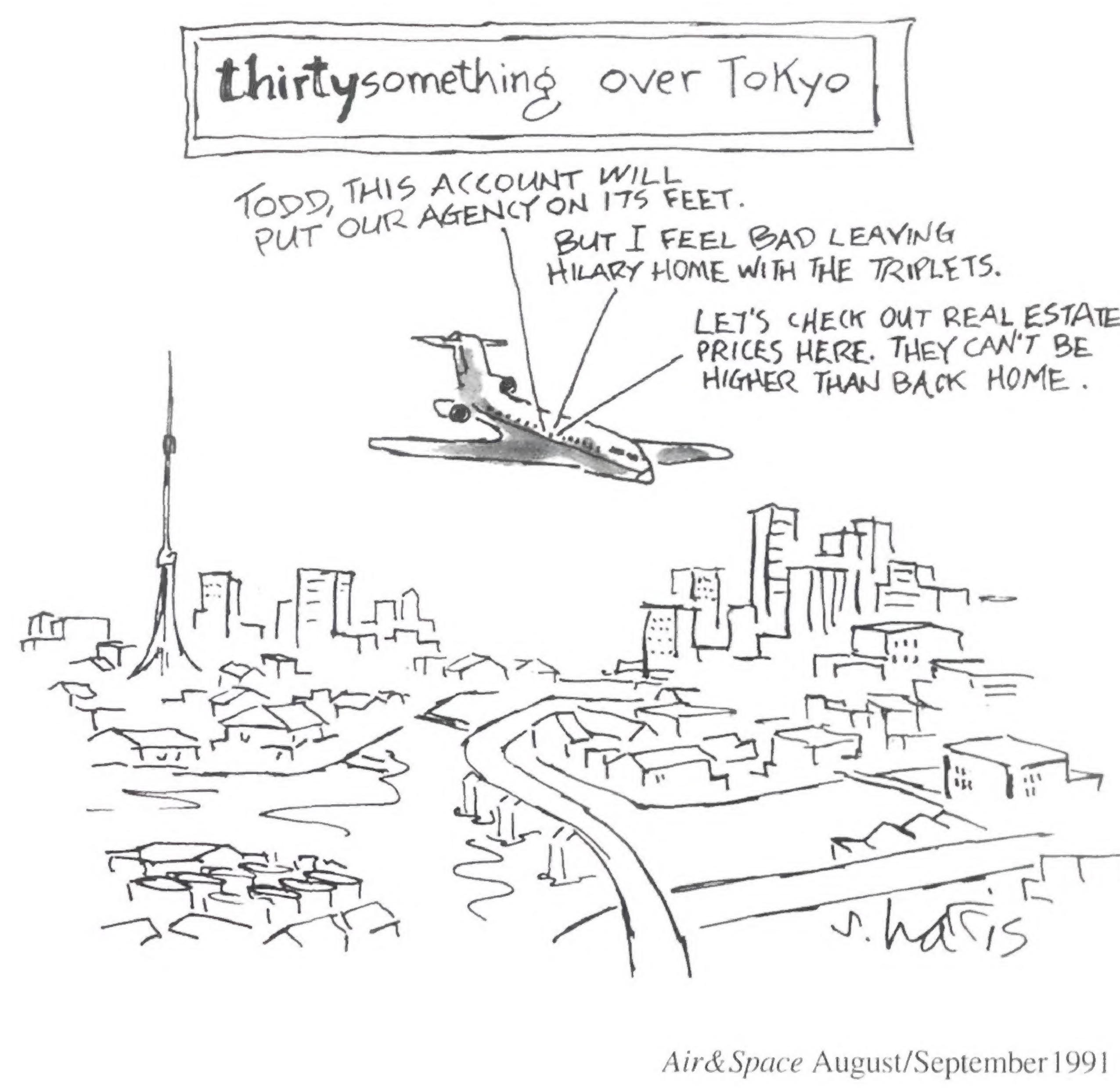
I'd like an author/pilot as skilled as Ron Dick to write a story on the P-47 Thunderbolt.

Charles D. Mohrle
Dallas, Texas

During World War II, I was stationed at the U.S. Naval Air Station at Moffett Field, south of San Francisco. Occasionally, a test pilot would take up our P-51 to blow the dust off. I can recall seeing the P-51 make a shallow dive and drag the field at about a hundred feet, that beautiful engine just purring. The sound gave me a little tingly feeling.

H.T. Chambliss Sr.
Mountain View, California

My first ride was in a P-51B with the narrow, hinged canopy. I got in, strapped



it on, and went. It flew a lot like a P-40 but was hotter and more crowded. Of course it would go like a bat out of hell, but I liked the P-40 better. It takes all kinds.

David H. Rust
Houston, Texas

I have often told my wife that in my reincarnation (if there is such a thing), I would love to be a P-51 pilot.

Harold Clevenger
Cincinnati, Ohio

A "yeee-haaah" to the Confederate Air Force for keeping those P-51s flying.

R.E. McCullough
Phoenix, Arizona

The Lighter Side of Camouflage

"Camouflage" (June/July) missed one visual ruse—pink. When the Ninth Air Force was desert-storming the Sahara in the spring of 1943, its B-25s and B-26s were painted a delicate pink. The light shade offered cover when viewed above the sandy African terrain. I flew a pink B-25 from Florida to Tunisia. Our crew was subjected to wolf whistles, waving handkerchiefs, and mock-flirtatious comments from the flight crews of olive drab aircraft along the way. We soon exchanged our "femininity" for a solid olive paint job.

Robert A. Spelman
Washington, D.C.

How to Fly a Barn Door

I found "The Legacy of the Lifting Body" by Stephan Wilkinson (April/May 1991) very interesting despite a couple of points that fly in the face of aerodynamics as I understand it. When Jerauld Gentry was piloting the M2-F1 behind a C-47 and began his "rocking motion," I suspect that he was encountering the wingtip vortex of the tow airplane rather than the propwash. Propwash (more logically called thrust turbulence since it also exists in jet wakes) is relatively light compared with wingtip vortices, especially when an airplane is traveling slowly, as it would be when towing.

Generating lift by separating a pair of air molecules with the leading edge of a wing, making the one traveling over the top "move faster to reach the trailing edge at the same time" as the one passing beneath is pure fantasy; the lifting bodies don't even have a clearly defined trailing edge. Lift is generated by the application of Newton's third law: for every action there is an equal and opposite reaction. The low-pressure area on top of the wing and the high-pressure area beneath the wing are both generated primarily by the wing's angle of attack, which accelerates the air it passes through in a downward direction. To maintain level flight, the mass of air accelerated down times its velocity must equal the pull of gravity on the body being lifted. My father used to tell me, "Given enough horsepower and the ability to control its angle of attack, you could fly a barn door." It wouldn't be very efficient, but he was right.

Tom Reinecke
Healdsburg, California

Stephan Wilkinson replies: Reinecke is probably right that Jerry Gentry ran into

wingtip vortices rather than propwash. As I remember, without consulting my filed-in-the-attic notes, "propwash" is what Jerry called it. That doesn't mean he was right. Both Jerry and I were probably indulging in the romantic inexactitude that too often permeates the language of the old-time aviator.

As for my description of molecules racing in a dead heat to the trailing edge to create lift, the classic explanation of Bernoulli's equation, which defines the production of lift, is: "Because the particles moving over the upper surface [of an airfoil] must travel a longer distance than those passing the lower surface, their velocity must be greater. According to Bernoulli's equation a low static pressure accompanies a high velocity pressure. Thus the fluid pressure acting on the upper surface of this airfoil is lower than the pressure acting on the lower surface. This lower static pressure on the upper surface results in an unbalance of the forces acting on the airfoil. This unbalance is a net force acting upward; it is lift." Those particles sound a lot like molecules to me. The above passage is from the old Modern Airmanship, *edited by Neil D. Van Sickle. Perhaps Bernoulli's work is so classic that it has been overtaken by Newton.*

Reinecke's father was right about the barn door.

Flying With Angel

"Jimmie Angel, Devil's Mountain, and the Lost River of Gold" (June/July 1991) made me recall three weeks in the spring of 1937 when Angel and I, among others, searched for an airplane of the Aéropostal Venezolana that had crashed in the jungle. Aboard was the commercial attaché of the U.S. legation at Caracas, where I was serving as Second Secretary. (The wreck was never discovered from the air; the survivors, which didn't include the attaché, came out on foot.) In the course of numerous flights I made with Jimmie in his Flamingo, I was treated to a spectacular close-up of the waterfall that became known as Angel Falls; paid a visit to Camarata, the Indian village at the foot of Auyán-Tepuí that served Jimmie and his mining associates as a base; and covered hundreds of square miles of territory where Jimmie claimed he had seen the remains of the Stinson in which Paul Redfern had attempted to fly to Rio de Janeiro from Brunswick, Georgia, in 1927. Angel was indeed a colorful character, a great spinner of yarns that may or may not have been true. He seemed to be a skilled bush pilot, but he

was not too concerned about maintenance. One pilot who took part in the search warned me half in jest to beware of flying in the Flamingo—the tail assembly was about to drop off.

Henry S. Villard
Los Angeles, California

Model Modifications

What a flood of memories your picture of the A-J 74 model airplane brought back (Soundings, June/July 1991). I logged many thousands of hours with these aircraft in my youth. But I never achieved the altitude indicated in the photograph and I could find no mention of this feat in any of the record books. Perhaps the unusual configuration of the empennage had something to do with this one's outstanding performance. The asymmetrical position of the horizontal stabilizer is an interesting modification, but even more intriguing is the reversed vertical stabilizer and rudder!

Richard E. Wirthman
Naperville, Illinois

Editors' reply: The innovative design changes were engineered by the crack assembly team here at Air & Space. *As far as the altitude achievement, our flight test facilities are located on the 10th floor, giving us a 100-foot head start. To order your own A-J 74, write to: American Junior Aircraft Company, P.O. Box 68132, Portland, OR 97268.*

Correction

In "A Horse of a Different Color" (sidebar to "Meet the Mustang," June/July 1991) Patricia Trenner notes that the P-82 was simply two P-51 fuselages on one wing. The time has come to retire this fable. If you look at accurate drawings of both craft, you can see how much longer the P-82's fuselage is behind the wing.

Dave Menard
Dayton, Ohio

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Hang Glider Homecoming

"…Just another sled ride. Then I hooked a boomer—800 up! Two grand over, I got dumped over the falls, coring sink fast. Next I was pickin' pine cones for ballast. That's it; scratch, baby, scraaatch!"

Welcome to the 19th Annual Hang Gliding Spectacular in Nag's Head, North Carolina, where for a few days last May you could sit on the dunes, swap flying stories, work on your tan, and critique the competition all at once; then at night unwind at either a reception (keg, hot dogs, nachos) or a street dance (band, parking lot, general good time).

This may be the world's oldest hang gliding competition, but it has the atmosphere of a beach party. Maybe that's because it was founded by someone who just wanted to learn how to hang glide. In 1973 Vic Powell ordered a glider through the mail. "It came with instructions on everything except how to fly it," he said. So he started the competition hoping to get some lessons, and one of the entrants—the man who owned the mail order company—became his instructor.

The current sponsor is Kitty Hawk Kites, the world's largest hang gliding school. Some 10,000 people earn their wings there each year, and most competitors are Kitty Hawk grads. "One of the most exciting parts is seeing my old friends who learned to fly here," said John Harris, the company's president. "It's like a real homecoming."

Probably no more so than for Francis Rogallo, a quiet and charming gentleman who retired from NASA over 20 years ago. During an afternoon competition he sat on a dune watching pilots soar over a designated course, racking up points for bravura technique and pinpoint landings. Every few minutes fliers young and old approached him, shook his hand, and thanked him profusely. And well they should: Rogallo is the engineer who developed the flexible wing, making him the father of hang gliding (see "Flexible Fliers," December 1987/January 1988). "I think it's just great to see all these people enjoying themselves," he said. "I just wish this had been around when I was young."

Fifty fliers competed in this year's Spectacular, their ages ranging from 17 to 63, their professions from schoolteacher to psychotherapist. Physically, they were a diverse bunch, some resembling marathoners, some skiers or swimmers. "You don't really need size," said Bob

CAROLINE SHEEN

Fener, a flier who just came to watch. "Brains are all you really need."

That, and a purist's desire to leave the ground without the aid of an engine or fuselage. All you want is a Dacron batwing and a good breeze sweeping over elevated ground. The first you can get for about $2,500; the other two are free here in Jockey's Ridge State Park, where the main dune, 140 feet above sea level, is the highest on the East Coast, and the wind blows off the Atlantic at 15 to 25 mph on a good day.

Receptions, street dances, and trophies aside, the lure of the Spectacular boiled down to something quite personal: the feel of running down the dunes and pushing the control bar out, the wind in your face, the straps tensing and stretching as you catch the lift, your feet leaving the ground. "You can use all the adjectives in the world," Harris said, "and you still can't describe it." Said Fener, "I always thought it was like dancing with the wind."

Or scraaatching.

—*William Triplett*

Update

Reactor Rescued From Red Tape

The Nuclear Regulatory Commission freed a Soviet nuclear reactor for shipment back to Moscow last May (In the Museum, June/July 1991). The Topaz II, here on a marketing mission, was granted a one-time exemption from NRC rules that prohibit the export of reactors to countries not included in a 1954 pact on the peaceful uses of atomic energy. Citing "the absence of fuel, moderator, and coolant," the NRC decided the reactor was not a true "utilization facility" and therefore was not bound by export regulations.

Set the Wayback Machine, Sherman

It's a trip into a timewarp: The original Mercury astronauts are on stage with a huge American flag as a backdrop. With them is comedian Bill Dana, in the guise of reluctant space traveler José Jiménez. Later, Walter Cronkite and Bob Hope will take the stage, and the voice of John Kennedy, exhorting the United States to

BETHANN THORNBURGH

go to the moon, will issue from the loudspeakers. Add the crew of the starship *Enterprise* in the audience and the 1960s ambiance is complete.

Except the *Enterprise* crew was from the 1990s version of "Star Trek," and the rest of the icons betrayed signs of aging—as Dana said, only partly in jest, the evening could be called "In Search of Ancient Astronauts." On May 3, 1991, they gathered at a Hilton in Washington, D.C., to celebrate the 30th anniversary of Alan Shepard's suborbital flight in *Freedom 7*. Thirty years? "Seven, eight, maybe ten," said Cronkite, "but 30 years? Absolutely no way."

Count it down again, Walter. Shepard thundered off the pad on May 5, 1961, becoming the first American in space. He and his Mercury compatriots (John Glenn, Deke Slayton, Scott Carpenter, Gus Grissom, Wally Schirra, and Gordon Cooper) became heroes in a country obsessed with the possibility of losing the space race to the Soviet Union. The United States ended up winning the sprint to the moon, and in 1971, Shepard, then an Apollo astronaut, chalked up another first: teeing off on the moon (see In the Museum, p. 17). "It's tough to play [golf] with astronauts," Bob Hope quipped. "They always count backwards."

The evening's black-tie dinner for a thousand guests had a dual purpose: to celebrate Shepard's anniversary and to award scholarships. The gala was sponsored by the Mercury 7 Foundation, a non-profit corporation founded in 1984 by the six surviving Mercury astronauts (Gus Grissom died in the Apollo 1 fire, but his widow Betty is one of the group's founders). This year 10 college students each received $7,500 for continuing education in science and technology.

After a dessert of chocolate Mercury capsules garnished with raspberries, Dana kicked off the evening's entertainment. His José Jiménez had been a favorite of the astronauts, and all six seemed to enjoy playing straight men as they grilled him at a mock press conference. (Noting the passage of time, Dana ordered them to "engage the interocular enhancers"—and they put on their glasses.) The salute to Shepard consisted of similar good-natured ribbing. Opening with the James Bond theme, a short film titled "How to Succeed in Business Without Really Flying (Much)" highlighted Shepard's life, culminating with his historic flight. Before the film was over, though, he was likened to space chimp HAM.

Even NASA administrator Richard Truly, in a fairly defensive speech, included a zinger ("Do you know what engineers use for birth control? Their personalities.") There were some pensive moments, though. The most heartfelt applause occurred during a film clip in which John Kennedy proclaimed, "We choose to go to the moon!" The nostalgia underscored the thrust of Truly's remarks: everyone always seems to ask NASA, "What have you done for us lately?" While Truly supported the space agency's present, the feeling—at least at this celebration—seemed to be that NASA's glory days are in the past.

—*Tom Huntington*

Update

At Face Value

The Face on Mars (Flights & Fancy, June/July 1991) has popped up in a series of 37 commemorative stamps issued by Sierra Leone. Though the set of stamps, which sells for about $135, has been advertised as having a potential worth of $10,000, *Linn's Stamp News* editor Michael Laurence says that until there is proof that the Face is indeed an alien creation, the stamp set is "overpriced and highly manipulated." Laurence told *Sky & Telescope* magazine that he was inundated with hate mail from investors who accused him of being narrow-minded.

NASM

Unsolved Mysteries

On December 5, 1945, a group of TBM Avenger torpedo bombers lumbered into the air from the Fort Lauderdale Naval Air Station on a routine three-hour training flight. Within hours the five aircraft and 14 crewmen vanished in the late afternoon haze, creating an aviation legend that added to the mystery of an area now called the Bermuda Triangle.

Last May, the puzzle of Flight 19's disappearance was thought to have been solved when Scientific Search Project, a Miami-based salvage concern hunting for sunken Spanish galleons, stumbled upon five Navy Avengers in some 750 feet of water 10 miles east of Fort Lauderdale. Crew members of the *Deep See,* using a camera-equipped probe, discovered the aircraft grouped within a mile of each other. The first Avenger sighted bore the markings "FT" for Fort Lauderdale/ Torpedo and another aircraft was numbered 28, the designation of Flight 19's leader, Lieutenant Charles Taylor.

However, Navy policy has been to recycle aircraft numbers and designations, so "FT 28" could have been assigned to half a dozen airplanes during the war. And subsequent investigation showed that the remaining aircraft are different Avenger types and belonged to different units. The "Return of the Lost Avengers" theory was debunked once and for all when Navy records revealed that all five aircraft were among eight bombers lost during low-level practice runs off Fort Lauderdale between 1943 and 1945. The area is full of the remains of such mishaps—some 140 Avengers alone were lost in accidents along a route from Fort Lauderdale to the Bahamas.

SSP had hoped to salvage the aircraft for museum display prior to its latest findings, but the Department of Justice filed a lawsuit in Miami thwarting the plans. Federal officials contend that the Navy never relinquished claim to the Avengers and that any salvaging is the government's responsibility.

If a mystery remains, says Larry Kusche, author of *The Disappearance of Flight 19,* it centers on where the aircraft went down, not why. He adds that the lore surrounding the disappearance—some think that the airplanes and crews were captured by UFOs—is based partly on fact but mostly on misinformation.

Kusche believes that Taylor, outbound for a navigational training flight around Grand Bahama Island, somehow got disoriented and thought he was over the Florida Keys. "Keep in mind that this was only his second or third flight out of Fort Lauderdale," he says. "Prior to that he had been leading training flights out of Miami bound for the Keys." Kusche points out that during a radio transmission, Taylor mistakenly referred to himself as "MT 28," indicating the Miami base.

At another point in the flight, Navy pilot Robert Cox, aloft in the Fort Lauderdale area, overheard Taylor and told him "to bring his plane around so that the [afternoon] sun was off his port wing," a maneuver that would eventually bring him up the coast to Fort Lauderdale, says Kusche. "The directions would have been fine had he been over the Keys, not the Bahamas." He adds that when Cox offered to escort Taylor, the lost aviator replied, "Don't come after me—I know where I am now."

The mystery deepened when some claimed to have heard Taylor report that he and his flight were in fog and flying toward a bright light, followed by "Don't come after me. I think they're from outer space." Kusche says there's no evidence to substantiate that version. He concludes that Taylor failed to trust his compass and flew further out to sea, where the group ran low on fuel and was forced to ditch. Any survivors probably succumbed to a storm that swept the area.

For Tony Vecchione of Dumont, New Jersey, both the find and its refutation are bittersweet. His late father, an aviation mechanic assigned to Fort Lauderdale, had helped keep Flight 19 airborne.

"I took him to see *Close Encounters of the Third Kind,"* he says, "and in that opening sequence where they find the airplanes, I remember his eyes widening and him whispering, 'Those were my planes' and 'I can still see their faces.' " Vecchione's father had been scheduled to fly a search mission on a Martin Mariner out of the nearby Banana River Naval Air Station hours after Flight 19 disappeared, but he was excused at the last minute. Shortly after takeoff, that aircraft also disappeared. Thirteen men were on board.

—*Albert J. Parisi*

Update

Mars Minibots

NASA is contemplating sending up to 20 tiny, inexpensive robots to Mars instead of one or two large, costly ones ("Getting Around on Mars," June/July 1991). Under consideration is a 1999 Delta launch of five 13-pound robotic "ants," which would be parachuted to the Martian surface to crawl around and collect samples. A return vehicle would fly the ants back to Earth for analysis.

Update

Antarctica Mid-Winter Rescue

A Navy rescue crew landed a National Science Foundation LC-130 transport at Antarctica's Williams Field last June, the first mid-winter landing there in 24 years ("Flying at the Bottom of the World," December 1989/January 1990). The LC-130, blessed with clear weather and light winds on its eight-hour flight, was guided to a landing by drums of burning kerosene. It remained on the Ross Ice Shelf only 90 minutes to evacuate a New Zealand engineer with ulcerative colitis.

Long-Term Parking

Situated in the shadow of California's Edwards Air Force Base, Mojave Airport has long been known as the home of the unconventional, housing everything from the brothers Rutan to the nation's only civilian test pilot school (see "Higher Learning," February/March 1990). Recently, it's also earned a reputation as the airline industry's version of a Roach Motel: airplanes fly in but they don't fly out.

Mojave is one of a handful of airports that are transforming themselves into commercial aviation boneyards—fields where unwanted airplanes are stored, often for years, until, if they're lucky, new buyers are found. And with the airline business falling on hard times lately, the boneyard business is booming.

As of June, Mojave was housing 80 forlorn airliners, among them Boeing 727s and 767s, McDonnell Douglas DC-9s, Lockheed L-1011s, and British Aerospace BAe 146s. The oldest residents are 18 ex-TWA Convair 880s that have been on the premises for nine years. But it wasn't until last spring, when the first of what would be roughly 50 Eastern airliners started one-way flights to Mojave, that the boom began.

Like other boneyards, such as Arizona's Marana, Kingman, and Davis-Monthan Air Force Base, boasts dry, salt-free weather that minimizes corrosion. It also offers rock-bottom storage prices: $150 a month for narrow-body airliners and $250 for chunkier models. "I'm hoping to stack a whole bunch of

DAN SABOVICH

airplanes here," says airport general manager Dan Sabovich. "We had an L-1011 come in yesterday from London. Long way to go for a parking space, don't you think? Me, I'd drive around the block a couple of times first."

Aerotest and OK Airline Support, both based on the field, are responsible for the airliners' maintenance, which consists of powering up the engines once a month if the airplane is expected to fly again soon or pickling the engines with a light oil if a long-term stay is anticipated. They move each airplane to avoid the formation of flat spots in the tires, and occasionally exercise the controls and auxiliary power units.

Although the boneyard migration has been a boon to these companies, workers admit to mixed feelings about their jobs. "In a way it's a shame," says Mike Potter, a former TWA captain who now runs OK. "To my new company—and I'm the president and one of the partners—this has been an economic windfall. But it's also depressing on a personal level because it's so upsetting to see an airplane and a company go down."

—Preston Lerner

Update

Astronaut Memorial Marred

"Space Mirror," a memorial that honors U.S. astronauts who died in the line of duty (Soundings, June/July 1991), developed cracks before its dedication ceremony. A clear acrylic substance used to fill in and clarify the cut-out names expanded, fracturing the granite. The damaged panels will be replaced at a cost of $12,000.

A MiG for the Museum

Perhaps an Egyptian pilot had been waiting to take off in it when the Israeli Army rolled into the Sinai peninsula during the 1973 war. Perhaps a disgruntled Soviet pilot defected with it. Perhaps it arrived via a "third party." Whatever happened, the U.S. Air Force isn't saying much about the source of the MiG-21 it recently gave to the National Air and Space Museum.

"We certainly didn't get it from the Soviets," says Murphy Donovan, a lieutenant colonel at Bolling Air Force Base in Washington, D.C. Donovan, who heads the base's Soviet Studies directorate, says the MiG-21 had been part of a classified display on Soviet weapons. The Air Force gave the airplane to the Museum when the display was dismantled due to changing world politics. His memory gets hazy when questioned about the MiG's prior history.

According to *Jane's All the World's Aircraft,* fewer than 500 MiG-21s remain in the Soviet tactical air forces. Designated "Fishbed" by NATO, the 1,385-mph aircraft was developed after the Korean War. Continually modified to meet changing demands, in its day the MiG-21 was one of the best fighters of its kind and the main adversary of the American F-4 Phantom over Vietnam. The Soviets produced some 8,000 in 17 models for service in 23 countries. Now the workhorse is nearing the end of its useful life, but it will probably remain in limited service until the end of the century.

Once the Air Force offered its MiG-21 to the Museum, restoration specialists from the Paul E. Garber Facility in Suitland, Maryland, visited the base to disassemble the jet, which measures almost 47 feet long (excluding the pitot boom), over 14 feet tall, and more than 23 feet in wingspan. It took the better part of a week to take off the wings, horizontal stabilizer, and tail cone. A flatbed truck transported the parts in two trips from Bolling to the Garber Facility.

While the MiG-21 is being refurbished it will have plenty of company. The Museum has several other Soviet aircraft: a MiG-15, the swept-wing jet fighter that fought the North American F-86 Sabre in the skies over Korea; an Antonov AN-2; and a Yak-18, which a North Korean defector delivered to the United States.

The Museum's plans for the MiG-21 are still undecided; for now the jet will remain on display at Garber.

—*David Savold*

This MiG-21 joins three other Soviet aircraft in the Museum's collection.

CAROLYN RUSSO

The Art of Glasnost

The press preview of "Art of the Cosmic Age" was a quiet occasion, evidence that there had been a good party at the reception the night before. For the artists who did show up, there were a handful of reporters with whom to discuss their work. The sparse media interest in the show, on display in the Flight and the Arts gallery through December, may explain why many of these artists—members of the International Association for Astronomical Arts and the U.S.S.R's Union of Artists—feel compelled to use their art to urge cooperation in the exploration of space.

A preoccupation with the troubles of this planet seems to have drained the public of any interest in visiting others. And many of the works in "Art of the Cosmic Age" take aim at this apathy. "We wanted to celebrate both countries' achievements and show what could be," said Robert McCall of "Starway of Humanity," an epic six- by 11-foot acrylic he painted with Soviet Andrei Sokolov. McCall and Sokolov, both leaders in the space art communities of their countries, created a panorama of low Earth orbit brimming with U.S. and Soviet spacecraft, including a shiny new space station Freedom, which may never become more than an image on canvas.

The show includes more than 70 paintings, drawings, and other works. It

Artifacts

NASA

An exhibit entitled "Astronaut Tools and Equipment" in the Apollo to the Moon gallery includes one tool, actually a replica, used to score a lunar first: on February 6, 1971, Alan Shepard used it to become the first man to hit a golf ball on the moon. (The original is at the museum of the U.S. Golf Association.) "It was the last thing I did before I crawled up the ladder," remembers Shepard, who as commander of Apollo 14 spent nearly 10 hours on the moon with lunar module pilot Edgar Mitchell, while Stuart Roosa remained aloft in lunar orbit. Shepard had an agreement with the mission director that if everything went well he could practice his golf swing with two golf balls he had smuggled into his spacesuit. "The suit is so confining I had to swing with only my right hand," says Shepard. He used a standard 6-iron head attached to the handle of the versatile tool the astronauts used to scoop up soil and rock samples. "I hit it down sun against the black sky so I could follow the trajectory," he says. On Earth the ball would have gone 35 yards and stayed up three or four seconds; in the moon's vacuum it traveled about 200 yards and stayed up close to 30 seconds. Shepard's next swing was less successful. "I shanked the second one and it rolled into a crater," he recalls. When asked about his current golf game, the first lunar golfer replies, "I'm still trying."

concludes with an Anatoliy Yakushin lithograph of Konstantin E. Tsiolkovsky, the scientist who formulated the basic laws of rocket propulsion, ushering in the age of space travel. Near the lithograph a 1913 quote from Tsiolkovsky makes the scenes of exploration seem more than wishful thinking: "Mankind will not remain on Earth forever, but in its quest of light and space will at first timidly penetrate beyond the confines of the atmosphere, and later conquer for itself all the space near the Sun."

—*Linda Shiner*

Museum Calendar

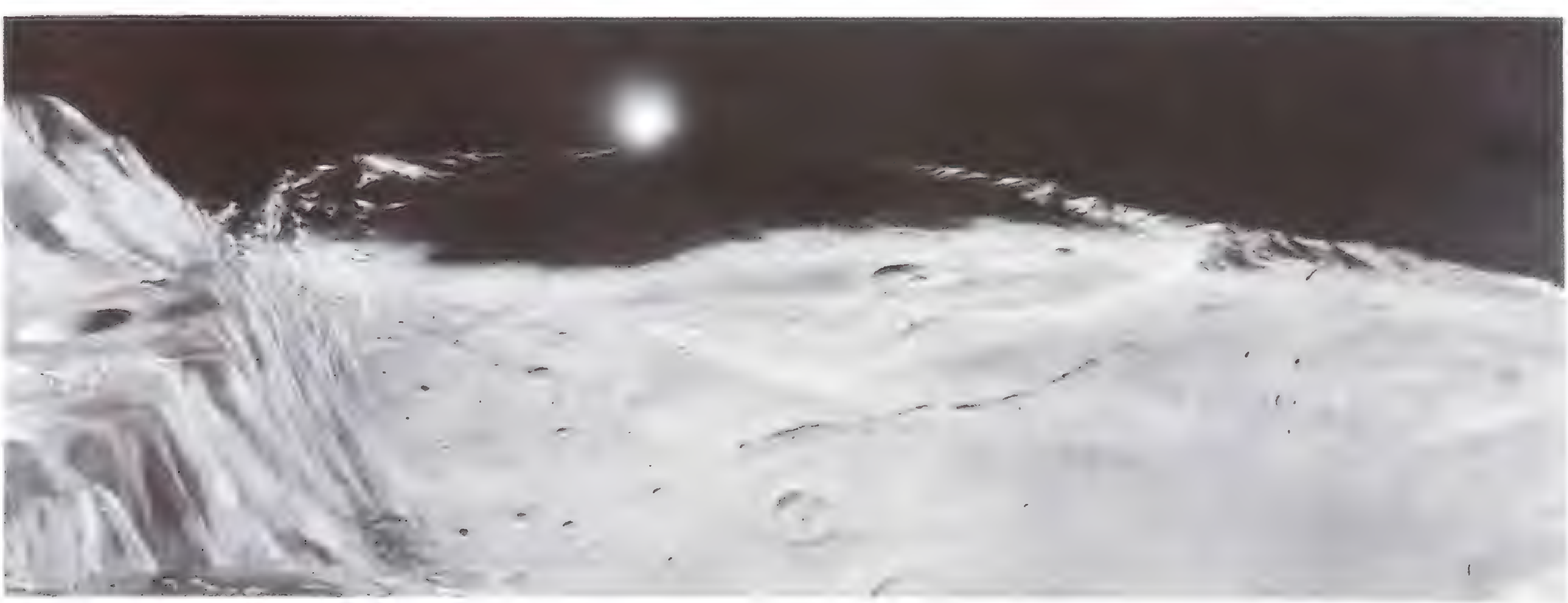
Except where noted, no tickets or reservations are required. To find out more, call Smithsonian Information at (202) 357-2700.

Museum Hours During the summer most Smithsonian museums will be open 9:30 a.m. to 7:30 p.m. daily. Starting September 3 the hours will return to 10 a.m. to 5:30 p.m.

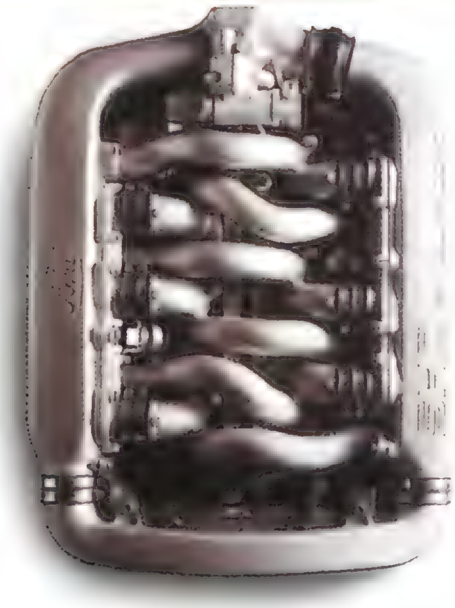
IMAX Summer Film Festival *Ring of Fire* and *Niagara* will be shown at the Langley Theater at 7:30 p.m. every day through September 2.

August 3 Monthly Sky Lecture: "Magellan and Venus." James Zimbelman, NASM. Einstein Planetarium, 9:30 a.m.

Planning a Smithsonian Visit? The Associates' Planning Packet is yours for the asking. Send a postcard to Associates' Reception Center, Smithsonian Institution, Washington, DC 20560, or call (202) 357-2700. Hearing-impaired visitors can use TDD and call (202) 357-1729. Begin your visit at the Associates' Reception Desk, located in the Smithsonian Castle, which is open 9 a.m. to 5:30 p.m.



"Mercury" by the French artist Jean-Michel Joly depicts an austere planet.



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In Memoriam

The SR-71 was close to perfect. After a 480-mile flight from Beale Air Force Base in California, the midnight-black airplane swooped down to about 300 feet above Burbank Tower, less than 30 seconds after its scheduled arrival time of 12 noon. It made an easy half-roll, then completed two more passes. The parking garage roof where I stood reverberated with cheers, but as the Blackbird came in for its final pass, a hundred feet off the runway, and then pulled up just beyond the tower, the crowd fell silent.

It was December 1989, and this flyby, a gift to Lockheed employees from Ben Rich, head of Advanced Development Projects (the Skunk Works), marked the beginning of the end of the SR-71. After much debate in Congress, the Blackbirds were about to be retired (see "The Blackbird's Wake," October/November 1990). The YF-12A, the earlier, single-seat version of the SR-71, first flew in August 1963 and the Blackbird in December 1964. It was still unsurpassed when it was retired in 1990, 24 years after it officially entered service.

As I watched the SR-71 that December day, I thought back to the airplane's flight-test beginnings in the early 1960s. I thought of Ben Rich, Ray Passon, Keith Beswick, and so many others whose lives were forever touched by this aircraft. I too was part of the Blackbird team, setting up housing, transportation, and communications—special measures due to the secrecy necessary. And above all of us was designer Kelly Johnson, who had a gift for sharing his ability to innovate and his drive to succeed. The unity of commitment we felt under leadership from Larry Bohanan in engineering and Dorsey Kammerer in production reached new intensity whenever Kelly arrived in the field. Sometimes he would good-

MICHAEL RODERICKS

naturedly arm-wrestle with people working there. His team members were hand-picked and fiercely loyal to him. He once offered $50 to anybody who could find an easy job to do. He got no takers.

When it came to their specialties, the people working on the Blackbird were the best in the company, perhaps in the country or even the world. The last word in reconnaissance airplanes, the SR-71 was capable of flying faster than Mach 3 and above 85,000 feet. In fact, the SR-71 flew so fast that even in the cold of those rarefied heights, the friction of the air heated its titanium skin to 550 degrees Fahrenheit.

The months leading up to the SR-71's flight testing were made up of interminable hours spent in the eye of a technology hurricane. We worked without fanfare but with a shared sense of purpose, and always a sense of the importance of our work. Because of the tight security requirements, we had to keep silent about what we were doing, even with our families. In those years we saw things that are still classified.

We worked at a Lockheed facility surrounded by the desert of California's Antelope Valley. Though usually serene, the desert could be besieged by sudden storms, with winds churning up clouds of brown sand that darkened the sky. Sometimes during a hot summer night the hangar was invaded by stag beetles, well-armored black insects with sharp jaws. Most nights they moved aimlessly in meandering circles, at other times resolutely, leaving smaller insects' body parts in their wake. Like the SR-71s, the beetles were the rulers of their domain.

At night the Blackbirds always looked sinister, even when in repose in the hangars, their access doors open, plumbing exposed, sharp-edged rudders turned. For effective control at Mach 3, the entire fin—not just a trailing edge panel—pivoted around a central shaft. In the hangar, these were often left at odd angles, lending an element of jauntiness, like a hat cocked to one side.

On the day the Blackbird took to the air for the first time, many of the ground crews showed up. I had worked all night, but sleep in those days seemed like nothing but a waste of time so I stayed to watch. The weather was perfect for a December day: clear and cold, with snow on the surrounding mountains. Somewhere around 8 a.m. the desert silence was shattered by the sound of the twin Buick V-8 engines used for the starters. Later, when the Blackbirds operated at their base at Beale, they had permanent start facilities in their hangars, but in the early days two highly modified 425-cubic-inch Buick Wildcats, an estimated 500 horsepower each, were used to turn a massive starter shaft that was inserted into first one, then the other of the SR-71's J-58 engines. One sound I shall never forget is that of those unmuffled Buicks holding steady at better than 6,000 rpm in excess of 15 seconds at a time, all hours of the day and night.

Starting the engines was no easy job. The J-58s' oil, formulated to lubricate at the high temperatures at Mach 3, was virtually solid at temperatures below 86 degrees. Before each flight, the oil had to be heated, and it took one hour to warm it 10 degrees. Because this maiden flight was on a cold December day, the Buicks were obliged to hold maximum speed a little longer than usual to get both J-58s running.

The ground crews, wearing headsets, ran through their checklists. Kelly Johnson stood by in his familiar dark blue suit and tie, smiling as he had a final word for the pilots.

The ambulances, the fire-rescue teams, and the fuel trucks stood at attendance. And waiting on the strip's edge, wheels chocked in line, were three Lockheed Constellations. Lockheed had provided two of the last 1049 models and a long-range 1649 for transportation to and from Palmdale or other places. Two of the three still had airline-configured interiors. Johnson had been behind the design of the Constellation too.

As I stood there waiting for the SR-71's first flight, I looked carefully around that little corner of the world. Watching the men who were there, I tried to find a simple way to describe their achievements, since I knew few would ever say much about themselves.

Most of them had been around Lockheed-built aircraft their whole careers. Many had been in ground crews for the P-38—another Johnson design—in the South Pacific during World War II. They were no strangers to the hard work necessary to get complex aircraft working correctly. Some of them told me that it wasn't until the P-38G model was produced that the Lightning had a cabin heater that worked well. But in the South Pacific, they said, you didn't worry about cabin heat—you wanted the P-38's concentrated nose-gun fire, along with speed, range, and rate of climb.

It had been a long time since these men had worked alongside primitive landing strips pocked with bomb craters. Now they were gray at the temples, their faces full of time, yet they still worked around the clock; they still considered a "well done" the only accolade needed.

One memory from the Blackbird's early days stands out for me. Several weeks after the first flight two test pilots were debating the performances of the SR-71 and the Lockheed's F-104 Starfighter—yet another Johnson airplane. At 40,000 feet a minute, the Starfighter was the current leader in rate of climb, as well as holder of numerous flight records.

The two pilots—blond, poker-faced Bob Gilliland and dark, stocky, ebullient Bill Park, later chief of Lockheed's test pilots and arguably more knowledgeable about the SR-71 than any other man alive—were just out of the Air Force. Like gladiators, they had a fine instinct for survival in a perilous profession. They knew each other's moves and could handle aircraft past design limits. As they compared the two airplanes, they talked about "some day soon, gettin' it on."

When the day of the contest finally arrived, only a few of us were watching. It was a typical spring morning, sometime around 10 a.m., and the desert was silent. I watched with a couple of members of Park's crew and some others just outside one of the hangars. The concrete beneath our feet was already hot.

Squinting through the glare of cloudless skies I saw two shapes reach the end of the runway and turn slowly into the wind. Down the runway they came, Park in the Blackbird, Gilliland following. The F-104 lifted off first. The Blackbird was off at 230 mph. Gilliland held the Starfighter safely aft of the Blackbird's port vertical fin.

The Mach 2.5 Starfighter and the young Blackbird flew like this a moment or two, until the pilots were satisfied with their alignment. Then they firewalled the throttles. There was a lag, both aircraft skidding side to side somewhat with the sudden burst of power. The tandem climbout gradually steepened to near-vertical, the Starfighter's superb J-79 matched against the Blackbird's massive twin Pratt & Whitneys, and the blue sky was pierced by a shrieking roar.

The two airplanes were together briefly, then the lighter F-104 pulled slightly out front. Gradually the Blackbird caught up and began to pull ahead. The gap grew wider as the two airplanes clawed their way into the sky. Finally, while the F-104 was still in view, the SR-71 became no more than a dark pinpoint, long gone and still pulling away.

A veteran crew chief standing next to me could only murmur, "Her enemies will never be natural."

—Jim Norris

Terminal Fatigue

"I just flew in from Vegas—and boy, are my arms tired!" goes the old joke, and we laugh, if we are drunk enough, because, of course, the experience of flying has nothing to do with flapping one's arms. Nowadays it suffices to sit back, relax, enjoy a complimentary soft drink or a nominally priced cocktail, and then pedal like hell.

But seriously, ladies and gentlemen. Air travel *is* exhausting. And yet all one is called upon to do is sit there, reading or snoozing, working or pretending to, gazing out the scratched window or tolerating the first-run second-rate movie deployed for our distraction. This, plus lamebrain pseudo-documentaries ("Exciting Breakthroughs in Textile Technology Mean Wider Choices for Consumers") and TV shows complete with commercials, marks the final stage of the devolution of onboard entertainment.

Still, taxing though it all may be, airline travel does not compare to coal mining or construction work. Why, since it consists of nothing more strenuous than pursuing sedentary activities in a too-small seat, do we get so tired? If it isn't all that sitting and eating and drinking, what is it that makes us feel as if we have indeed traveled?

For the answer, look to the terminals through which we pass prior to departure and subsequent to arrival. For it's not flight that is so depleting—it's airports.

Begin with the fact that all buildings acquire residual auras and vibrational "echoes" derived from the activities that occur within them. Thus cathedrals feel pious and otherworldly and bowling alleys feel clangorous and hearty. The terminology for this phenomenon is imprecise, since I'm making it all up, but you know what I mean. So it goes with airports, which, like train and bus stations, are structures whose main purpose is to get people to leave them. Thus, to enter an airport, however casually or with whatever amount of ample time you have allotted to reach your gate and board without haste, is to enter a process of expediting, of getting-on-with-it, of motion. It is a process best captured, I think, in the words of Frankie Laine, who sang—for the ages—"Head 'em up, move 'em out, Rawhide." To merely cross an airport's threshold is to be impregnated, if you will, with the high-frequency radiation of transitoriness.

Plus, what sort of element do we encounter in airports? Travelers. Banging up against a few dozen travelers has the net result of making almost anyone feel as if he too is traveling, particularly if he is going somewhere.

DAVID CLARK

Bear in mind, too, that on your flight you are exposed to a single air transportation phenomenon, whereas in the airport you are exposed to a dozen, a hundred. The PA drones on about one arrival or departure or boarding or last call after another; monitors continuously display flight numbers, gates, and times like stock tickers; arriving passengers swarm out of gates and greet loved ones with a wave and an embrace while, at an adjacent area, departing passengers file into the gangway after taking leave of loved ones with an embrace and a wave. Everybody is either coming or going, and even those waiting will soon be going, or meeting and greeting those coming, and then leaving.

And these are just the civilians. Amid this business hustle and vacation bustle, the professionals perform, with grim efficiency or happy ineptitude, their national air transportation jobs. Flight crews cruise past in various livery, the men toting their glamorously utilitarian flight cases, the women pulling their irritating little collapsible luggage dollies that always work for them and never for you. In the cafeteria and bars and snack counters, concession workers tirelessly perform their daily chores, serving up high-quality prices for low, low food. These, if nothing else, instill in the most stoic customer the urge to travel—to another country, another airport, and another cafeteria, bar, and snack counter.

And then there are the airplanes themselves. These silver behemoths, with their swept wings and sleek noses, with their constantly changing flight schedules, ticket prices, and corporate bailout schemes—who can contemplate them and hear their whining roar without that thrill of fear, vertigo, and wonder our ancestors experienced 10 million years ago (or whenever it was) in the face of a woolly mammoth or a triceratops (or whatever it was our ancestors faced)?

Everything about airports embodies, manifests, and imbues us with a sense of motion, from the Krishna Consciousness devotees, promising transports of ecstasy, to the smartly uniformed "gals" (no other word will do) at the car rental booths, to the anonymous personnel tootling smugly along in those little *beep-beep* golf-cartish trucks. Compared with a stroll through the tumult of an airport, flying itself is an anticlimax, a sort of high-tech waiting.

Landing merely combines the mild suspense of a state lottery with the jolt and strain of an amusement park ride. Oh, the takeoff has its thrill. But it feels like a reward, a prize for having made it through the airport. Shuffling onto the airplane and dropping into our seat feels like the *end* of travel, and the beginning of a well-deserved rest—albeit one in a rather peculiar restaurant with a limited menu and unsatisfactory seating, moving 550 mph at a height of 33,000 feet. Nice scenery, though.

—Ellis Weiner

Doctor's Orders

by Nancy Shute

Grounded. It's a word every pilot dreads–and it's often a flight surgeon's duty to say it.

Jim Sullivan never thought his career as a naval aviator would hinge on this: hanging off a gurney like a falling angel, his eyes fixed on the linoleum below.

"You doing all right?" asked Ron Centner, leaning hard on Sullivan's right leg to keep him from dropping head-first onto the floor. Centner, a Navy flight surgeon, controlled much more than Sullivan's immediate safety. Here, in a small examining room on an airbase in Iceland, Centner held the flier's future in his hands.

Until now, Sullivan's Navy career had gone smoothly: after graduation from the U.S. Naval Academy, he gained a coveted slot in aviation and was deployed to the wild, frozen north with his P-3C Orion squadron. In two weeks he'd have a chance for a promotion from navigator to tactical officer, in command of all the electronics and weapons his P-3C employed to hunt submarines in the North Atlantic.

Sullivan's squadron, VP-24, had moved to Keflavik from its home base in Jacksonville, Florida, in the dark of February. Although he had worn a hat and had taken his vitamins, he'd come down with a cold. So one morning, he went to the flightline clinic. "I thought I could head off being grounded," Sullivan recalls. A corpsman had checked him out, and as Sullivan began pulling up his flightsuit, "I just felt kind of hot. Then I heard them talking, saying, 'Are you all right?' " He'd fainted.

That swoon instantly barred Sullivan from flying. The Navy wouldn't let him back in the air until it was sure he wouldn't faint again. Blood tests for dehydration, a common cause of fainting, were inconclusive. The next step, according to a set of medical standards used as a reference by flight surgeons and issued by the Naval Aeronautical Medicine Institute (NAMI) in Pensacola, Florida, was an "unexplained syncope" series, a battery of tests designed to ferret out any abnormalities in Sullivan's circulatory system. As his doctor and flight surgeon, Centner was responsible for certifying that the navigator was healthy enough to fly—or grounding him for life. This test held the key.

So here was this 25-year-old aviator, a vision of health, wired up at 7:30 in the morning like some Frankenstein experiment, the tip of his left index finger wearing a little plastic pulse sensor, a blood pressure cuff circling his arm, and electrodes glued to his chest and legs. Petty Officer David Orskey, the squadron's medical corpsman, tended monitors that updated the lieutenant's vital statistics at regular intervals.

"Okay, go ahead and record another [heart] rhythm strip, blood pressure, and pulse," Centner said. Orskey punched a button, and the electrocardiogram monitor spat out a strip of white tape. Sullivan stared at the floor, his face turning pink. His numbers scarcely budged.

"Okay, I'm going to pull you back up now," Centner said. He slid an arm under Sullivan's shoulders and hoisted him onto the bed. "No dizziness? Lightheaded? No? Good."

Orskey punched out another EKG strip and handed it to the doc. "Looks good," Centner said, scribbling on the readout. "Everything's looking good."

The tests continued, with Sullivan obediently squatting, standing, holding his breath, plunging his hands into a tub of ice water, turning his head left

Flight Surgeon Ron Centner tests Jim Sullivan to find out why the navigator fainted during a routine checkup.


OES Maintenance Chart
OLYMPUS
DURA-CUF
CRITIKON

CHAD SLATTERY (2)

Centner wears two sets of wings: before attending flight surgeon school, he flew P-3C Orions.

and right as the doctor massaged his carotid artery, and performing a Valsalva maneuver, the hold-your-breath-and-clench technique pilots use to force blood to their heads and counteract G forces. Centner talked his charge through every move: "You're going about 54 breaths a minute," he said during the hyperventilation test. "That's good. I'm going to, in about five seconds, ask you to go real fast and real rapid. Now! Deep and fast! Deep and fast! Get ready to record—go! Okay, you can stop. Are you okay?"

"Feeling a little lightheaded," Sullivan said, still panting.

"Feeling any tunnel vision, flashing lights?"

The mainstay of the Navy's land-based anti-submarine force, Lockheed P-3C Orions entered service in June 1962. Navy squadron VP-24 sweeps the northern Atlantic from its base in Iceland, using the airplane's complex electronic systems—including radar and detectors that sense changes in the earth's magnetic field—to seek out and track maritime traffic on the ocean's surface and beneath it.

Sullivan laughed. "Just lightheaded, that's all."

After about 90 minutes, the test was over. "What I have to do at this point is talk to NAMI," Centner told Sullivan. "Everything looks really good. I don't think there'll be any problem at all. You're still grounded right now for your cold anyway. I hope that we'll have an answer by Tuesday." Sullivan smiled, zipped up his flightsuit, and headed out into the cold wind, his career in the hands of the doctors.

On a break, Centner luxuriates in a hot spring near Keflavik that Icelanders call "the Blue Lagoon."

Military flight surgeon Ron Centner is a rare breed of physician—trained not only to treat aviators but also to fly with them. Though the title has survived from a time when "surgeons" pulled teeth and bandaged fingers, flight surgeons don't spend their careers in flying operating rooms. Figuring out why one navigator fainted is just part of Centner's most important responsibility: ensuring that aviators are fit to fly safely.

"My job is to keep people up," Centner says. "Or if they're not up, to get 'em up. It's tough sometimes."

Pilots see it another way: to them, the doctor's job is to devise ever more devious reasons to keep them grounded. It's an impression they form early on, when Navy flight school candidates undergo a week-long physical at NAMI designed to weed out all but the most perfect specimens. The "NAMI whammy" bounces hopefuls for the most minor of defects: a long-healed high school football knee injury, nearsightedness (no worse than 20/30 is passing for an aviator candidate, but once they earn their wings they can fly on 20/70, as long as it's correctable). And throughout their careers, aviators can be temporarily downed by any doctor—not just flight surgeons—for a head cold or for taking a single aspirin. It takes a flight surgeon to return them to flying status.

CHAD SLATTERY

"The flight surgeon is always a threat," says Captain Ronald Ohslund, a flight surgeon who was in command of NAMI until June 1990. "He's the guy who can terminate an aviator's career." Although aviators will swear they would never fly if they weren't 100 percent fit, few would down themselves for feeling, say, 96 percent. Or less. Pilots want to fly as much as they want to breathe.

"Aviators are cheaters and liars," Ohslund says, grinning. "If they really want to fly, they'll do anything from memorizing the eye chart to wearing contact lenses."

Centner appreciates just how they feel. He piloted P-3s for nine years though "I was never one of those guys that knew I *had* to fly," he says, with a trace of Kentucky twang. Centner joined ROTC to pay his tuition at the University of Louisville, then headed for Navy aviation because he liked the "upbeat, upscale" community. He decided to go for P-3s, even though the slow turboprop patrol planes were derided by most jet jocks and helo pilots as low-testosterone dinosaurs. "I liked the team concept of P-3s," Centner says. "I got lucky. I loved it."

At 29, after two tours and deployments overseas, Centner reconsidered his Navy career. He couldn't see himself manning a desk at the Pentagon, the usual fate of pilots after commanding a squadron. He bailed out, moved back to Villa Hills, Kentucky, and hit the job interview circuit. But sales rep jobs didn't look like much fun after tracking submarines and "rigging"—circling Soviet trawlers at mast height. A cousin who had left the Baptist ministry for medical school suggested that Centner do the same. Other people in a position to influence him agreed. That's when he first thought about becoming a flight surgeon.

In April 1978, while Centner was in the Azores, one of the squadron's P-3s crashed, killing all seven aboard, including his roommate and his flight engineer. Centner helped the squadron's flight surgeon investigate the accident. Although the cause was never found, it got Centner thinking about why mishaps occur.

"Things like that don't have to happen," he says today. "Accidents happen because people make mistakes. I don't want to see anybody get killed. I've gone through that before."

Centner's responsibility to monitor his squadron's health takes in all areas—including morale.

After medical school at the University of Kentucky and a year of internship in family medicine, Centner attended the Navy's flight surgeon school in Pensacola and pinned a second set of wings above the first. The two sets of wings drew double-takes when he first arrived at VP-24; pilots-turned-flight-surgeons are rare birds. Centner is even rarer because his twin brother, Don, also flew P-3s, also went to med school, and also serves as a flight surgeon with a P-3 squadron in Jacksonville. The Navy Medical Command sometimes gets the two of them mixed up.

Keflavik, a NATO airbase with a resident U.S. naval air station, is pinned to a bleak spit of lava on Iceland's southwest corner. Winters are notoriously harsh: the sky brightens for just a few hours a day, illuminating the freezing rain. With winds commonly approaching 50 mph, residents have to bolt lengths of seatbelt webbing to the bottoms of their car doors to keep them from being ripped off their hinges. Heavy steel dumpsters have become airborne, and the week before Centner's squadron arrived, a storm with 120-mph gusts lifted roofs off buildings and crushed a storage hut.

Doc Centner's flightline clinic had an examination table, a steel cabinet full of cold remedies and a half-gone carton of condoms, and his copies of *A Manual of Skin Diseases* and *Psychiatry Made Ridiculously Simple.* Not much, but enough. "Most of the stuff in sick call we've been able to handle here," he said. He tried to prepare the troops for the climate with briefings on how to avoid frostbite. But wind and ice combined to form a greater threat: two mechanics broke their arms falling. And the squadron racked up an unusually high number of allergies and sinus infections. Several crewmen suffered burns when they got too close to the renowned Icelandic geysers. Much of the work was routine, though, and the flightline clinic, two tiny green rooms just off the greasy clamor of the hangar, hosted a steady stream of aches, worries, and the Keflavik deployment blues.

Jim Sullivan's problem began as a minor ailment, then unexpectedly escalated into a career-threatening disability. While waiting for NAMI to evaluate his case, he had plenty of time to consider a future without wings. "All these things are going through my head," Sullivan said one afternoon while hanging out at the squadron hangar. "What if I wasn't able to fly anymore? Would I take a ground job, or what?

"I don't think what's happening here is going to be much of a problem," he continued; he's 25 and thinks he's immortal. "It's just something the doc had to do. If the test hadn't gone well"—he paused for a moment to contemplate the unthinkable—"but it did. Not to fly

MEDFORD TAYLOR

In flight familiarization training, a military flight surgeon becomes just another student.

for a month or two months—you'd go crazy."

But getting Sullivan aloft again took more than a little effort on Centner's part in lobbying NAMI. "We'll have to NPQ [not physically qualified] him and go ahead with a waiver," Centner explained. "What it means for him is that he'll have to get a full flight physical every year instead of every three years." Later that week, Centner called NAMI again. Sullivan was cleared to fly.

Centner is fully aware of the paradox of his role as both enforcer and advocate: "Regardless of whether it makes them grounded or not, you have to give them the medical care they need. You have to win them over: 'You know, you really ought not be flying on that, man; don't take the chance. Don't ruin your career, man.' I try to come down easy and help them understand what's going on. I try to turn it to their benefit."

By all measures, Centner succeeds. When an enlisted man worried about a sinus infection barges into the flightline clinic long after office hours, Centner gives him his undivided attention for 15 minutes, then calls the next morning to see how he's feeling. Centner sums up his work succinctly: "It's still an art, you know. It's not a science."

A good bedside manner seems to come naturally to Centner. He's a square who's fond of Louis L'Amour novels and Engelbert Humperdinck records, yet he earned the nickname "Elvis" in his old squadron because of his ability to mimic the King. (Of his impersonation, Centner says, "It's more of a gyration.")

"I've seen a lot of flight surgeons, and he's probably the best," says VP-24 commander Mike Holmes, who has been flying P-3s since 1973. At least once a day, Holmes says, the doc intercepts him to discuss a patient. "Seventy-five percent of being a good flight surgeon is the ability to sit down and be earnest with people, spend time with them. Quality time, so they feel like they're being taken care of. You won't find a finer guy than Centner." He pauses. "If only I could get him to talk in English." He shakes his head at the thought of Centner's medicalese.

Between sick call at the flightline clinic and two days serving as general physician at the base hospital, Centner put in 70 to 80 hours a week, with no days off. But one radiantly clear Sunday morning in mid-March, Centner took a break. He arrived at the hangar at 9 a.m., suited up, and took the left seat of a P-3C. With visitors aboard, the 10-man crew elected to practice formation flying rather than their usual mission: searching for submarines with the complex electronics that pack the P-3C. After takeoff Centner climbed the airplane until it was level at 9,000 feet. Mike Holmes, always ready to abandon his desk for the cockpit, sat on the right. After a while, Centner broke off from the formation momentarily, scooted down to within a few hundred feet of the whitecapped water, then ascended to rejoin the other P-3C. He carved a steeply banked turn that pulled some Gs. "That one was a 2.8!" a crewman shouted.

Back in formation, the two airplanes traversed the Greenland ice pack, its glare so white it hurt the eyes, then turned east, back to Iceland's spectacularly rocky coast and glacial valleys. It was the finest sightseeing flight in the world. After five hours, a brief jaunt for a P-3, the crew headed for home and the Brass Nut, a bar in the bachelor officers' quarters. This, they agreed as they popped open their beers, is what flying is all about.

Flight surgeons did not exist at the start of World War I, when three times as many aviators were killed by mishaps as by enemy action. "If you could walk in and out and breathed, you flew," says Colonel Russell B. Ray-

man, former chief of aerospace medicine for the U.S. Air Force. "That's why we lost so many airplanes. There were no standards."

In 1917 the Army founded the world's first aeromedical laboratory, a facility in Mineola, Long Island, staffed by what would become the first flight surgeons. The researchers worked by the seat of their pants to devise tests and physical standards for pilots. Not all their notions were winners. One early test spun prospective pilots on a piano stool. If they threw up (a normal reaction), they failed. In another challenge, candidates held a needle between thumb and forefinger while a gun was fired behind them. "If he stuck himself and bled, that was considered bad," Rayman says.

But the Army researchers also developed many now-classic elements of aviation medicine, including flight physicals, oxygen equipment, goggles, safety harnesses, and flightsuits. When the Mineola flight surgeons were dispatched to the squadrons in France, the aviators' death and accident rates fell immediately.

Between the world wars, the idea that a pilot's health was crucial to safety spread into civilian aviation. World War II stimulated an enormous interest in the subject, with researchers working feverishly to devise better oxygen systems and protective gear. Mental stresses of combat flying became a key concern, as did the loss of vision and consciousness induced by G forces in high-speed air combat.

The American Medical Association granted aviation medicine its formal recognition as a specialty after a series of discussions in the late 1950s. Later, research expanded with funding from the newly formed National Aeronautics and Space Administration. Joseph P. Kerwin, a Navy pilot and flight surgeon, became the first M.D. in space when he flew on Skylab 2 in 1973. Today the specialty is called aerospace medicine; aviation medicine survives as a sub-discipline within it.

The Navy trained its flight surgeons at the Army's school from 1921 until 1939, when it launched its own school and research center in Pensacola. Today, each branch of the service has its own system for recruiting and deploying flight surgeons, and they differ in

"You Just Jump on the Helo and Go"

No flight surgeon experienced the Gulf war the way Major Rhonda Cornum did. When the 229th Aviation Regiment sent a battalion of Apache helicopters to Saudi Arabia last August, she was asked to go along. She had known many of the 100 pilots and 200 flight crew members since their flight school days, and counted many close friends among them. "They'd come to my house," recalls Cornum, a 36-year-old who had worked as a biochemist for the Army before going to medical school. "I'd drive in my driveway and find the guys swimming in my pool." Her husband Kory, an Air Force flight surgeon, headed east with another unit a week later, leaving Rhonda Cornum's daughter, 14-year-old Regan, in the care of her father in North Dakota.

On January 10, Cornum's unit was repositioned to prepare for the ground war in Iraq. She taught the helicopter crews how to use chemical warfare antidotes and performed air evacuations of soldiers injured in non-combat accidents. On February 27, three days after the ground war began, a call came in: an Air Force F-16 pilot was down in Iraq with a broken leg. Cornum hopped on a Blackhawk rescue helicopter along with two gunners and three Pathfinders—soldiers specially trained to control air operations in a combat zone. She almost didn't come back.

Her helicopter, escorted by two Apache gunships, had entered hostile territory flying low and following commands from an Airborne Early Warning and Control System (AWACS) radar plane overhead. Cornum had watched green tracer fire rise from an Iraqi bunker. The pilot banked to avoid it, but the helicopter was hit. "We're going in," the pilot called, and the Blackhawk went down.

Cornum found herself wedged in the wreckage, unsure if she was dead or alive. She managed to wriggle free, only to be nabbed by four Iraqi Republican Guards. One grabbed her right arm. She screamed. "The pain wasn't the worst. The worst was the sound of your bone going crunch."

Cornum had suffered two broken arms, a broken finger, torn ligaments in her right knee, and, though she didn't realize it at the time, a bullet in her right shoulder. She didn't receive any medical treatment for four days, and she almost died from the loss of blood. At one point she was sure the Iraqis were going to execute her. Instead, she and the other two survivors of the crash were taken to Baghdad, where she was held in isolation, with no idea what was happening in the war or to her.

On March 5 the Iraqis released her. Television reports showed a slender brunette, arms swaddled, stepping off an airplane in Saudi Arabia and being greeted by General Norman Schwarzkopf. The war had moved so quickly that few people were aware that she had been taken prisoner. In Pensacola, Kathy Moeller looked up from the TV and screamed to her husband: "Oh my god, Mike, that's Rhonda." They had been friends in medical school. Moeller says she wasn't surprised to learn that a flight surgeon had been in the thick of battle. "It's pretty routine that when a crash call comes in, you just jump on the helo and go."

By early May, Cornum had undergone successful surgery to repair her knee. Her peppery energy seemed fully restored. She complained jokingly that the bad knee kept her from doing pushups. Later, she recalled how she and her husband had discussed what they would do if they were captured in Iraq. They had even talked about swallowing their wedding rings so that the Iraqis wouldn't take them. She never got the chance. "With two broken arms it's hard to swallow your ring," she said. But she had no regrets, although she was separated from her daughter. "She suffered more than we did," Cornum said. Her flight surgeon's uniform now sports a Purple Heart and a Prisoner of War Medal.


AP/WIDE WORLD PHOTOS

Cornum on the day she was liberated.

how much they require doctors to know about piloting an aircraft. The Army, which has 148 active-duty flight surgeons, provides a six-week training course that emphasizes the peculiarities of Army aviation, such as flying with night-vision goggles. In 1988 the Army dropped pilot training for flight surgeons for budgetary reasons, but it now plans to reinstate a four-week course in UH-1 helicopters, according to Captain David D. Krieger, course director for the flight surgeon school at Fort Rucker, Alabama. "We like to get primary care, family practice type people," Krieger says. "It's a total concept of taking care of pilots."

The Air Force employs roughly 600 flight surgeons, 460 of whom have taken a seven-week course in aerospace medicine that includes an orientation flight in a T-37 or T-38 jet trainer. The other 140 are super "specialty trained" flight surgeons, with a full four-year residency in aerospace medicine, including a master's in public health and hands-on flight training.

The Navy has the most exhaustive indoctrination, a six-month period that includes aerospace and general medicine courses at NAMI, survival training, and seven weeks of flight training in T-34C turboprop and TH-57 helicopter trainers. The Navy has 363 flight surgeon slots, including 42 who serve on carriers as chief medical officers; they do a full residency in aerospace medicine similar to the Air Force's specialty trained flight surgeons.

All three branches design their training to inoculate physicians with enough of flying's method and myth to immunize them against the worst antipathies of aviators. "The new flight surgeon's biggest challenge is to win over the pilots," Rayman says. "Most flight surgeons are extremely good at that. Their interest in aviation is very important."

The offer of a few years spent flying in the back seat of an F-14 is an effective recruiting tool for a military perpetually hard up for physicians. The Navy's brochure puts it this way: "For the individual who likes to fly and wants a bit of adventure, [flight surgery] presents numerous opportunities for new and unique experience, travel, and individualism in the daily practice of medicine. It's not for everyone."

Not for everyone—Tim Mologne read that and was hooked. As a graduate of the Naval Academy and the son of an Army surgeon, he knew something about military medicine even before he graduated from medical school, but there was a lot he wanted to know about flying. In the spring of 1990, Mologne, a 28-year-old with a wrestler's build, went to the Navy's primary flight school at Whiting Field, north of Pensacola, for flight training. There, he sat along with student pilots in a shack near the runway, huddling with instructors who sketched the mysteries of aerodynamics on small chalkboards. The tension was as thick as the fog that shrouded the field.

MEDFORD TAYLOR (2)

The Navy's seven-week flying course for flight surgeons even includes the challenge of helicopter training.

Mologne was delighted by his first flights in the two-seat T-34C trainer, but he wanted more—he wanted to solo. "I know medicine is what's going to make me happy, but I want to see what that thrill is like," he said at the time.

"Even if I don't get a solo, I know some of the pressure it is to be a pilot. I knew it was a tough job, but now you see they have a ton of things to do, and how thinking about things like marital problems can affect their performance. There's a lot of pressure."

Mologne got his thrill, soloing the turboprop trainer just before graduation in April 1990. "It was pretty neat," he crowed. "No stress at all."

Not all flight surgeons at Pensacola are learning to fly. Kathy Moeller has a different mission: taking care of student pilots. She is the primary family physician for two training squadrons and their families.

Moeller's kid-sister face belies a fierce determination. When she graduated from the Naval Academy, the Navy offered her a nice job as a choir director. She politely told them what they could do with the choir and asked for medical school instead. The Navy's first female flight surgeons graduated in 1974, so Moeller was following a firmly established precedent.

At Pensacola, Moeller performs flight physicals designed to determine who can handle the stresses of jets, who would be happier in a P-3 team situation, or how a student who'd freaked out during a carrier landing can salvage his career. Much of the serious work is done by what she calls "hallway medicine"—students and instructors snagging her on the run, away from the formality of the examination room. "They like to be in control, and it's hard to feel that way when your pants are around your ankles," she says.

She has done her share of the most painful task of all: official accident investigations, including one at Cherry Point, North Carolina, in which a flight surgeon was killed. The accident she remembers most vividly is a 1989 crash on the training carrier *Lexington* in which five died and 19 were injured. Moeller not only investigated the crash, she survived it.

She had just landed on the *Lex* in the backseat of a T-2C jet trainer when another airplane hit the carrier's superstructure, raining flaming debris across the deck. Moeller's trainer was parked and chocked beneath the superstructure, so she and the pilot couldn't eject or take off. "I thought he was going to hit us," Moeller recalls. "My thought

With his instructor, Tim Mologne heads out to a haze-bound T-34C for a training flight.


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MEDFORD TAYLOR

Mologne (left), shown with instructor Mark DiAntonio, soloed in a T-34C, then shipped out to the Red Sea.

was, *Oh my god, my baby.* My baby was only six weeks old. There wasn't a doggone thing we could do but sit there and watch it happen.

"There was fire all around us and they were spraying us with foam," she says. "The deck officer told us to get the hell out of there." She scrambled out and ran for the aft elevator and the sick bay, where she snapped into doctor mode, helping the ship's two physicians triage the wounded. Later she flew off the ship with one of the most severely injured crewmen. "I was suctioning, ventilating the whole way, trying to keep him alive," she recalls. Despite her best efforts, the crewman later died. Moeller's husband had been called into the hospital ashore and told only that there had been mass casualties on the *Lex.* It wasn't until an hour later that he learned his wife was safe.

"When you start losing friends and have to pick up the pieces, it has an impact," Moeller says. "This is a dangerous business." In every flight surgeon's mind is the idea that by practicing the best possible preventive medicine, they can help stop the accidents. "Making sure they're not taking risks, grounding them when they shouldn't be flying—we're in the business of saving lives," Moeller says.

Although a few flight surgeons elect to specialize in aerospace medicine, most go on to specialize in other fields, either within the military medical system or as civilians. Moeller is beginning a residency in radiology, Mologne plans to specialize in orthopedic surgery, and Centner is considering family practice. But for all flight surgeons, the Gulf war forever changed any idea they may have had that their job is just a way to practice medicine, see the world, and rack up some flying hours.

Medical personnel were among the first to be sent to the Gulf. Centner was spared because the P-3s were needed to continue their anti-submarine surveillance. Moeller was called in late November, the week her third child was due, and told that she and her husband should sign their wills and be ready to roll in January. They scrambled to find a babysitter to help her mother and sister care for their children. But for Kathy Moeller, final orders to the Gulf never came.

Mologne, having scored a coveted slot with a carrier air wing out of Oceana Naval Air Station in Virginia Beach, Virginia, figured he would get lots of time in the backseat in an F-14 or an A-6. But to his disappointment, he soon realized that because of the way this wing operated, he would have to struggle to fly his required four hours a month. He bunked six floors below the pilots and had little time to build up rapport with the four squadrons in his care. "If I had a busy day in the clinic I had no contact at all with the aviators," he recalls. "If they had a problem they'd call me on the phone."

The *Kennedy* was one of the first ships to deploy to the Gulf. Parked in the Red Sea and waiting for war, Mologne assisted with appendectomies, splinted broken wrists, and generally performed the role of country doctor for a small town of 5,000. Then, to his surprise, the admiral announced on the intercom that they had battle orders. "I didn't sleep the first night," Mologne says. "I kept thinking that some of these good friends are not coming home."

The medical staff had drilled exhaustively for a flood of casualties. They never came. "I don't think we even had a plane hit with a bullet," says Mologne. "If you had no access to the news you wouldn't know a war was going on."

The mundane schedule and weird sense of isolation grated on him. He wished he was out in the desert, doing search and rescue with a Marine helo squadron. "It's just tough when you're sitting there and it's one in the afternoon, you're done with work for the day, and you're in the middle of a war. People were writing me saying 'Please be safe,' and I thought, *If you only knew what I was doing.*"

But Mologne soon realized that if the isolation and the routine irritated him, it tormented the enlisted men, many still in their teens and all of them separated from their families. He put in more time than he ever imagined he would counseling lonely and depressed sailors. "They would come down to Medical and read these letters: 'The state's taken our kid away and the house is being repossessed.' I would talk to them for an hour or two, pat them on the back, and say, 'See you around.' "

That didn't feel like wartime doctoring to him. It wasn't until the ship returned to Norfolk in April and he was walking downtown that Mologne realized that those pats on the back may have been the most important medicine he administered. He crossed paths with a dozen sailors, vaguely familiar faces among the thousands he had treated. When they spotted him they would beam and show him off to their families—"Hey, this is Doc Mologne!"—as if he were General Colin Powell. "That was good," he says.

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The Floating World at Zero G

Without gravity, nothing–not even breathing–can be taken for granted.

by Doug Stewart

Illustrations by Ben Juarez

After taking off on the last Mercury mission, Gordon Cooper settled in for a good night's sleep halfway through his journey. Compared with most of the duties of spaceflight, it seemed an easy enough undertaking. But Cooper ended up having to wedge his hands beneath his safety harness to keep his arms from floating around and striking switches on the instrument panel.

Since Cooper's flight, sleeping in space has become a routine matter—maybe too routine. When carrying out an especially boring or tiring task, some astronauts have nodded off—only they didn't really nod; they simply closed their eyes and stopped moving. "There are none of the waking mechanisms we're used to on Earth," says Joseph Allen, who flew on the shuttle in 1984. "Your head doesn't fall over. Pencils don't drop from your fingers and hit the floor to wake you up."

Pencils can, however, waft away. Allen discovered that if you pull open a drawer full of items that haven't been strapped down, everything drifts away and soon "you have a real slow-motion slapstick on your hands, because you just can't get to all of them and tuck them under your arms and between your legs fast enough."

Such oddities of life in microgravity are details that NASA didn't always foresee when spaceflight began. Now, after studying how astronauts lived and worked aboard Skylab, which hosted three-man crews on long-term missions from 1973 to 1974, the agency is pushing to build the space station Freedom, a permanent human abode in low Earth orbit to study how humans can thrive in weightlessness month after month. While Congressional budgetary pressures have threatened Freedom's future, the space community still hopes to launch some kind of manned orbiting laboratory. "If we're ever to colonize the solar system, we need to know more about living in microgravity," says Harvey Willenberg, chief scientist for civil space programs at Boeing Aerospace, the space station's primary contractor. "Can you survive a year of weightlessness? Yes you can. Can you spend a year getting to Mars and be productive the moment you get there? That's the real question." A space station, says Willenberg, would help answer it. So while funds remain, NASA continues its research to develop a safe, familiar, even homey habitation for Earthlings who venture where they don't naturally belong.

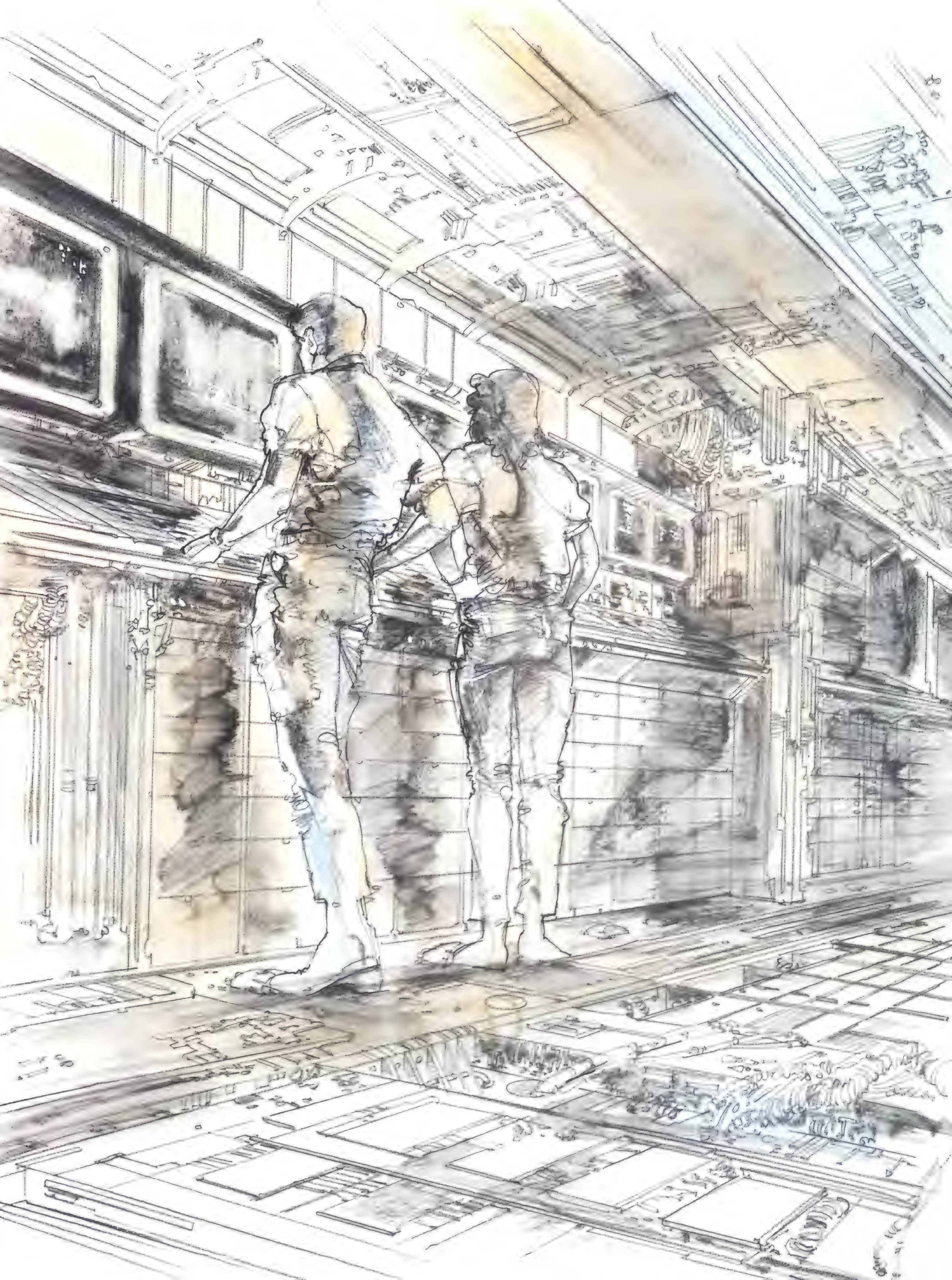
Of course, all the research on Earth can't make a space station truly familiar. "Zero gravity is so bizarre," says Allen, "that even if [a spacecraft] looked like your mother's house, it doesn't feel like your mother's house because you float, and the floating is so extraordinary. At no moment do you think, *I'm in a nice office on the ground.* Never."

Will It Look Like Home?

So far, Skylab has been the only U.S. spacecraft worthy of the designation "space station." An enormous can that had originally been designed as a Saturn rocket's fuel tank, Skylab had over 12,000 cubic feet of habitable space. Equal to the volume of a decent three-bedroom house, Skylab was over 50 times roomier than the Apollo command module. The crews settled in for long stays, the final one an 84-day marathon. "Unless you got on Skylab," says Pete Conrad, its first commander, "you don't have a real appreciation for zero G." If you're an American, that is.

Soviet cosmonauts have spent far more hours in space than U.S. astronauts, and in the age of *glasnost,* the American and Soviet space communities are engaged in a relatively open exchange of human factors engineering data. According to Jack Stokes, a human factors engineer at NASA's Marshall Space Flight Center in Huntsville, Alabama, cosmonaut experience aboard the Soviet space station Mir supports the ideas of U.S. space station designers. "It helps to have somebody up there who's trying it and proving that we're probably off on the right track," he says.

To keep astronauts from drifting about, space station designs include strategically placed foot restraints.



Of the lessons NASA has learned from its own astronauts, one of the biggest is that it must provide for their psychological well-being. In the days of Skylab, astronauts were largely a band of macho fighter pilots, and they were expected to perform accordingly. "NASA didn't downplay psychological factors. It ignored them," says Bill Pogue, a former fighter pilot and Skylab astronaut who now advises Boeing on how *not* to lay out a spacecraft. He is still grumpy about the subject. Skylab wouldn't have had its one window if renowned industrial designer Raymond Loewy, creator of the Lucky Strike bull's-eye and a one-time NASA consultant, hadn't insisted. In 1973, after Skylab's final crew demanded a day off after six weeks of escalating work orders, Pogue spent several hours doing nothing more than gazing out that window.

Any future space station will certainly have at least one window, as well as a few other comforts of home. Or at least an aerospace engineer's approximation of the comforts of home. Freedom's final layout is uncertain, but the design presently calls for a series of large metal cans linked at their ends like sausages. Work areas and eating-sleeping-leisure quarters will be housed in separate links, the "lab module" and "hab module" in NASA-speak. Plans call for a washer and dryer (to avoid wobbling the craft, the washer will squeeze clothes in a bladder instead of spinning them), a Nautilus-style exerciser, and a refrigerator-freezer and trash compactor. Budget constraints, however, have already doomed plans for private closet-size sleeping quarters, including a "togetherness suite," a pair of sleeping compartments with a central partition that married occupants could remove to engage in zero-G intimacies.

NASA's inclusion of such quasi-comforts as washers and trash compactors isn't an attempt to pamper space station crews but rather a sign of its current awareness that a happy, comfortable astronaut is a productive astronaut. The agency has even hired consultants to determine the wall colors that would be most *simpatico* with orbital life. Pink is said to be restful, though it's hard to imagine astronauts at ease in an all-pink decor. "I don't live in a pink house," says Allen. "I can't imagine why I would want to be in a pink ship."

Whatever color NASA chooses, the space station interior will still resemble a not especially luxurious mobile home: narrow, rectangular corridors with surprisingly smooth and almost featureless walls. The barrenness is the first hint that the space station is to be parked not in someone's backyard but in a perpetual freefall around Earth. Accordingly, its walls will form a sort of squash court off which humans and other loose objects will gently carom.

When the fare floats, eating takes some forethought. Drinking requires a straw and special bag-like containers.

When Down Is Up

In zero G, one's eyes have to do what one's helpless inner ear no longer can, so NASA now takes pains to give space travelers a strong visual sense of up and down. It wasn't always so. Aboard Skylab, labels and electrical switches ran in different directions. One workstation was positioned sideways to the rest of the spacecraft. The toilet seat was set midway up a wall, like a window. "It was really squirrelly," says Pogue. Even the space shuttle, on crowded flights, forces some astronauts to sleep strapped against the underside of a crewmate's bunk. Without gravity you can theoretically sleep anywhere, but as shuttle payload specialist Byron Lichtenberg points out, "It's hard trying to sleep like a bat on the ceiling." Awakening his first morning in space, Lichtenberg looked around at his upside-down environs and felt overwhelmingly nauseous.

"You don't *have* to have tables on the floor. They can be on the walls or the ceiling," says Brand Griffin, Boeing's project manager for advanced civil space systems. "But in space you like things to be pretty terrestrial." To keep crews oriented, Freedom's designers plan to have fluorescent lights running the length of the "ceiling," tables attached to the floor, and windows—not toilets—appearing on the walls.

Astronauts need time off to enjoy the pleasures of spaceflight, such as simple recreational floating.

Zero G is sometimes a real nuisance. Opening a drawer, for instance, can result in a ten-minute chase.

Getting Around; Staying Put

Skylab's crews found they didn't need handholds and ladders to get around; they quickly learned to push off with one hand and float directly to their destinations. Says Pete Conrad, "You could look across the tank and say, 'I want to do three 360s and land on my feet over in that corner' and do it." His crewmate Joe Kerwin never went anywhere in Skylab without executing a few slow rolls in transit. One time Conrad exercised by running laps around the tank's circular walls on his hands.

Though the space shuttle is a bit more crowded, there's still room to maneuver. After heading aloft for the first time aboard *Columbia* in 1983, Lichtenberg remembers unbuckling himself from his seat and trying to stand up. "I immediately shot right up to the ceiling," he says. "I said to Owen Garriott, 'Hey, we're not in zero gravity—we're in *negative* gravity!' " By the time they're back on Earth, astronauts have acquired the habit of trying to get out of their chairs by pressing lightly on the armrests. (Similarly, after returning to Earth, one astronaut let go of his coffee mug in midair and was surprised when it crashed to the floor.)

Using the lessons of Skylab, space station designers have kept waist straps and handholds to a minimum. "We found out from Skylab that if you can nail a guy's feet down well enough, he can basically do anything he does on Earth," says Jack Stokes. He doesn't actually recommend using nails; to eat, use a computer, or do some other stationary task, astronauts now slip their stockinged feet into loops or wedges attached to the floor. Similarly, a single Velcro head strap suffices to keep sleeping astronauts from drifting out toward the ventilation ducts. For some tasks, however, a firmer anchor is required. When Pogue first tried to use a screwdriver in space, "the screw didn't twist; I did." He had to strap down both legs and his free arm before he could get the screw to turn. Spacecraft now pack electric screwdrivers.

One item you won't find on any space station is a chair. In the weightlessness of space, the human body assumes what NASA calls the space neutral body posture: shoulders hunch, arms float forward, legs and knees bend slightly. "You don't want to design things that pull the astronauts out of that position," says Boeing's Griffin. A workstation chair that flew on Skylab required astronauts to keep their abdominal muscles flexed; the chair was soon removed.

The Bathroom

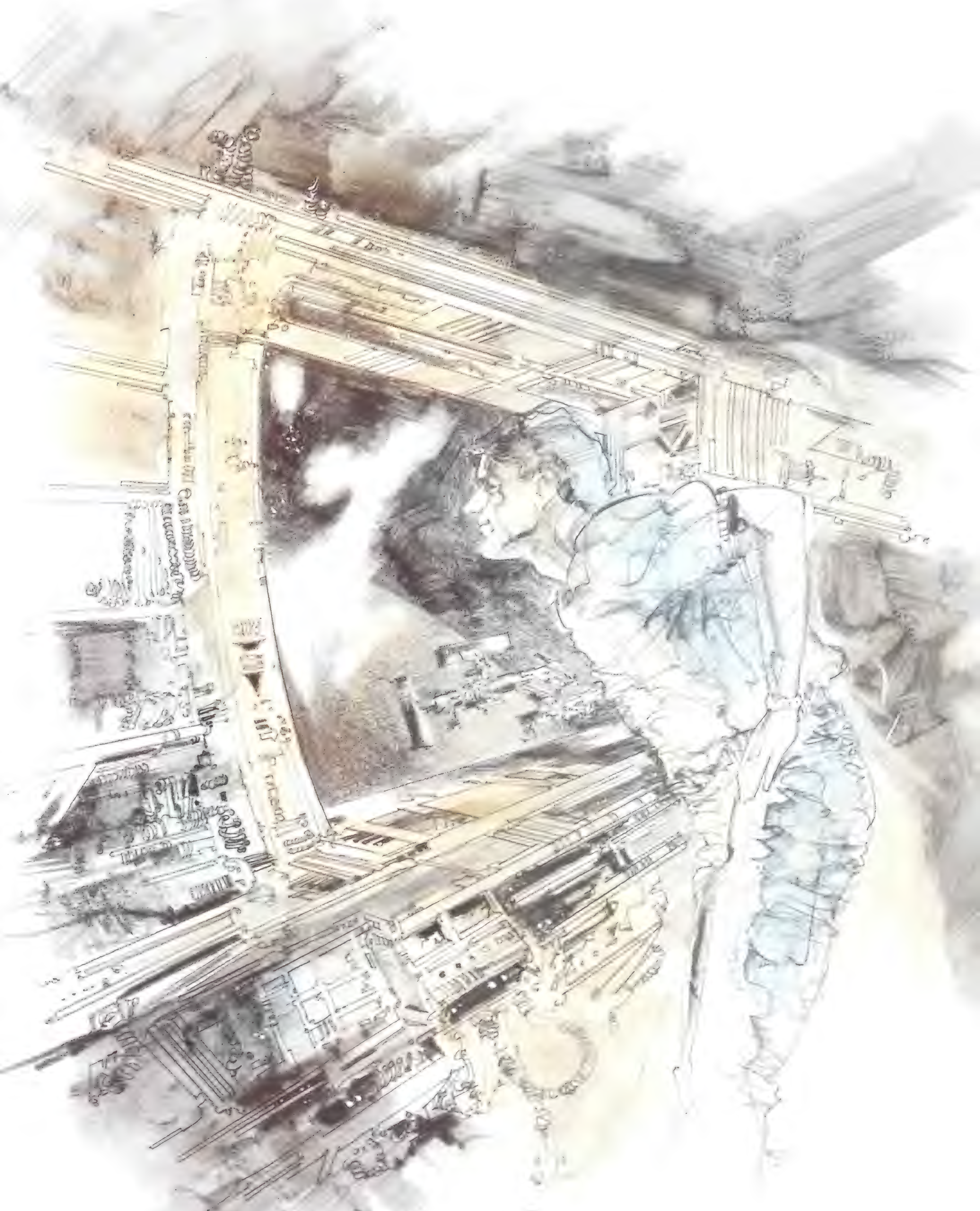
Hygiene in space has come a long way since Gemini and Apollo astronauts defecated into plastic bags with adhesive-lined tops. Any space station will certainly have what NASA refers to as the "waste management compartment"—a space toilet. It will be similar to the one that shuttle astronauts use, which is surprisingly Earth-like in appearance and function. Astronauts sit down on the shuttle toilet to perform what those in the industry call "normal bowel evacuation," while air suction guides the waste into a tank. (Because everything in microgravity floats, it is crucial to make a good seal between buttocks and toilet seat; cushioned bars across the thigh help keep the astronaut in place.) For urination, astronauts use a funnel-equipped hose attached to the toilet. On the space station, solids will be compressed and freeze-dried for return to Earth, and since water will be in short supply, urine will be purified and used for laundry and bathing.

Next to the toilet is the full-body cleansing compartment, or shower stall. This, too, will rely on airflow to make its drain work. In use, water will emerge in spherical blobs from a hand-held shower head.

Those Little Irritations

Although astronauts almost universally agree with Pete Conrad's assessment of zero G as "better than Disneyland," it has its irritations. Many have to do with the absence of convection currents, the eddies of air that gravity keeps in motion on Earth. In a spacecraft, hot air doesn't rise. Neither

A window is necessary for a space traveler's well-being, especially on longer missions.



You can't lie down in space, so a bed is useless. Sleeping gear is a bag, which can be tethered to a wall.

do bubbles, which remain in beverages and cause the drinker to belch. And since sweat doesn't drip off the body, it tends to collect on the skin in ever-thickening sheets. After a session on Skylab's treadmill one day, Pogue washed all but his head before starting his work. He soon noticed a putrid odor and looked around for rotting food. "Then I realized I was smelling the cocoon of smelly air around my head," he says. A more dangerous effect is the buildup of exhaled carbon dioxide around an astronaut's face; fortunately, onboard ventilation systems keep air safely circulating.

The effects of microgravity, however, aren't always irritating. A favorite recreation is playing with one's food. Surprisingly, ordinary utensils work fine in space, although food sticks to both sides. Instead of carrying food all the way to their mouths, Earth-style, some experienced astronauts use their spoons as slow-motion food catapults.

Although drinking a cup of coffee seems like the most natural thing on Earth, in space it won't work. If you tipped the cup back to take a drink, the weightless coffee would not roll out, so astronauts suck their beverages out of plastic bags with straws. Joe Allen enjoyed studying the behavior of orange juice after it leaked out of its container and sat quivering in a perfect golden sphere at the end of his straw. It resembled, he says, "the world's weakest, wimpiest Jell-O." Allen offers the following advisory to fellow zero-G investigators: "Don't let your curiosity tempt you into exploring a larger clump of liquid than you're prepared to drink later." If you don't catch up to your blob with a straw, it eventually attaches itself to the nearest wall or window.

Without gravity, crumbs, lint, fingernail clippings, bookmarks, contents of pockets, and the occasional sleeping astronaut drift freely throughout a spacecraft. On Skylab, the air moved up almost imperceptibly toward a grate over a ventilation intake near the top of the tank. Two or three days after it was lost, a pencil or set of reading glasses would appear on the grate. "We called it the Lost and Found," recalls Gerald Carr, Skylab 4's commander. Crewmate Pogue adds that debris from mealtime tended to nest in the metal grid ceiling above the galley, where it was hard to wipe up. After a few months, the galley ceiling "looked like the bottom of a birdcage." "It's those little things that drive them berserk," says human factors engineer Stokes.

It's Stokes' job to predict the problems, major and minor, that crop up once the tug of gravity disappears. Though he has never been to space, Stokes has flown two and a half Earth orbits' worth of parabolic arcs aboard converted KC-135 tanker aircraft, airborne roller coasters that offer zero G in hellraising 30-second snatches (see Above & Beyond, April/May 1990). Many pieces of equipment destined for the space station are tried out by human subjects in a KC-135's padded cargo bay. Including the solid-waste toilet, Stokes recalls. Yes, in 30 seconds.

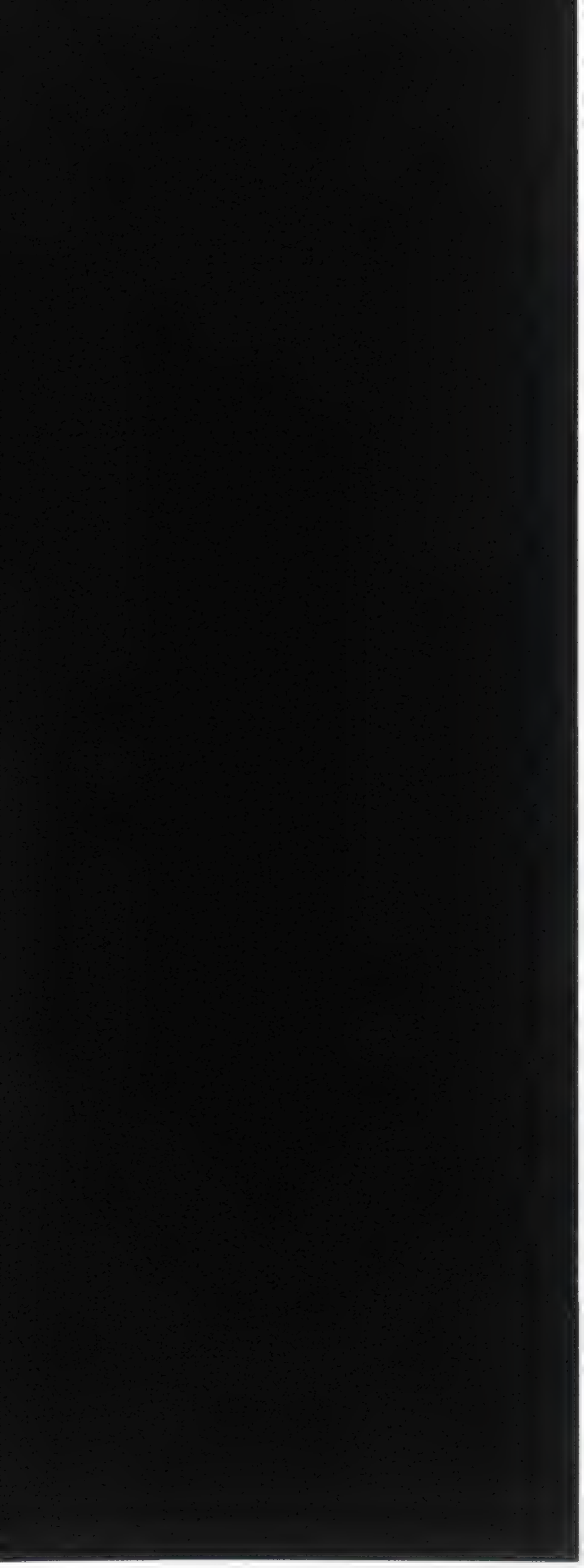
Such embarrassments are necessary if astronauts are to soar, of course. The whole idea of airborne testing is to make living and working in weightlessness easy and unremarkable for ordinary folk. If the designers do their job, says Brand Griffin, the space station will be a boring place to live. "You'll get your Nobel prize for what you do in the laboratory module, but the rest will be as exciting as a refrigerator," he says. Stokes agrees: "[Freedom] is just a laboratory now, and a very well-equipped laboratory. It just happens to be located in a strange place."

"You Have Made Yourself Immortal"

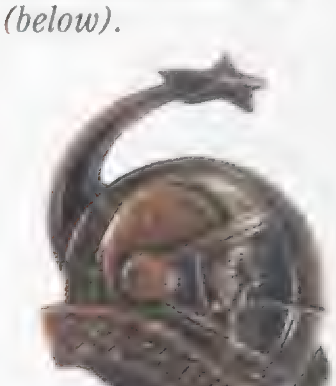
Yuri Gagarin–Cosmonaut Number One–died in 1968, but a celebration 30 years after his historic flight shows that his memory lives on.

Text by Tom Huntington

Photographs by Lee Battaglia



In a country racked by change, reverence for Yuri Gagarin remains a constant. His image dominates a museum at the Soviet mission control facility at Kaliningrad (opposite). At Baikonur, a rocket like the Vostok 1 that sent Gagarin into space stands at the launch pad in tribute (left). Perhaps hoping the luster would rub off on him, beleaguered Soviet president Mikhail Gorbachev addressed the Moscow ceremony that marked the 30th anniversary of Gagarin's flight (above). Those not invited to the ceremony could still buy a commemorative pin (below).



They take their heroes seriously in the Soviet Union, and cosmonaut Yuri Gagarin occupies a position near the top of the pantheon. On April 21, 1961, Gagarin gave his country an undisputed space triumph when he became the first man in space. "You have made yourself immortal," premier Nikita Khrushchev told him after his 108-minute, single-orbit flight.

The son of collective farmers, Gagarin was portrayed as the ideal Communist. Everyone who met him, wrote fellow cosmonaut Andriyan Nikolayev, "found something to admire in him. Some saw his indefatigable optimism, others a flexible and searching mind, still others valour and stamina, or,

perhaps, modesty and simplicity and a touchingly warm attitude to other people."

Gagarin, who would have turned 57 this year, died in an airplane crash in 1968. The world has changed much in the years since his death. Men have walked on the moon, and some of Gagarin's countrymen have spent more than a year orbiting Earth aboard the Soviet space station Mir. The Cold War, which provided impetus for the space race waged between the U.S.S.R. and the United States in the 1960s, has ended. The Soviet Union itself faces a troubled present and an uncertain future. Even the Soviet space program, which has marched on steadily through the decades, is being closely scrutinized by government economists.

In the town of Leninsk, cosmonauts, astronauts, and other fans gathered to honor Gagarin's memory with everything from brass bands to camel races (above).

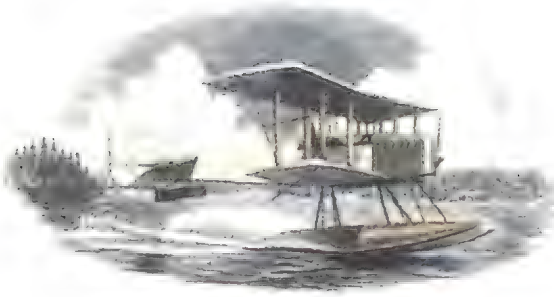
Alexei Leonov (right) and Valentina Tereshkova (far right) gave and received autographs at the Leninsk event. They have both scored space firsts for their country: Leonov was the first man to walk in space and Tereshkova was the first woman in space.

The Buran shuttle, carried atop its Antonov transport, was a highlight for the crowd at Leninsk (right).

The Leninsk festivities also featured a Bison bomber, converted into a cargo carrier for rocket components (below).

When Gagarin flew into space 30 years ago, cosmonauts and astronauts were worlds apart. With that gap closing, U.S. and Soviet space travelers mingled at Leninsk (left). At right, astronaut Walter Cunningham and fiancée Dot Vannerson get acquainted with fliers of another type—Soviet falcons and their owners.

Through it all, Yuri Gagarin's name remains undimmed. Last April a number of his fellow space travelers gathered in Moscow to celebrate the 30th anniversary of his flight. Sponsored by the Soviet chapter of the Association of Space Explorers (see "The Hundred-Mile-High Club," April/May 1988), the commemoration attracted space voyagers from 15 countries, including 19 U.S. astronauts. One of the Soviet chapter's guests was *Air & Space/Smithsonian* picture editor Lee Battaglia, whose photographs prove that Khrushchev was right.

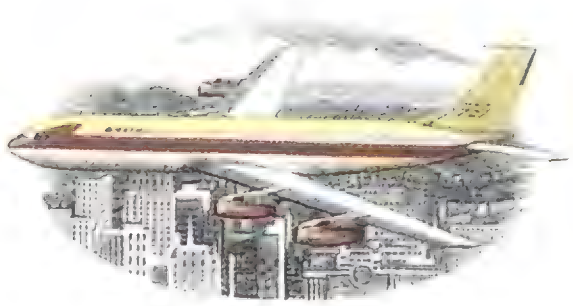


B&W

After taking his first airplane ride in 1914, William Boeing said, "I think we can build a better airplane." Two years later, he did

Boeing B-17

The Flying Fortress. Flight crews swore by them, the enemy was awed by them. They, more than any other aircraft, helped turn the tide of World War II



Boeing 707

The airliner that launched the world into the jet age. The patriarch of the Boeing family of planes. The original now belongs to the Smithsonian

Boeing 747

She is called the Queen of the Skies. And she rules with unprecedented range and extra-ordinary comfort, flying 400 passengers one-third of the way around the world

Boeing Monomail

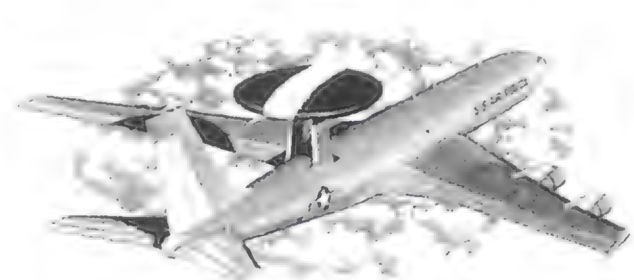
All-metal, single-wing, no external bracing. With the advent of the Monomail, the biplane had flown its course

Boeing B-52

From being the backbone of the Strategic Air Command to its recent success in the Gulf War, the Stratofortress continues to be an integral part of our nation's defense

Boeing Chinook

Fly by day or night. Land on earth or sea. Transport 44 troops or lift 14 tons. Simply put, it's the most versatile helicopter in the world

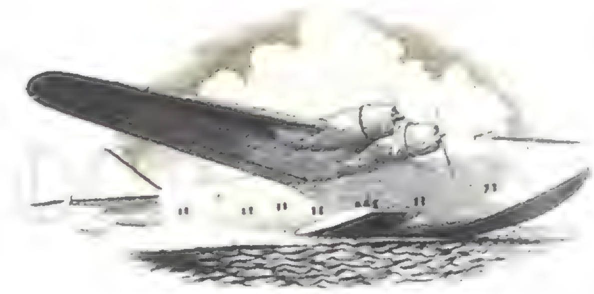


Boeing AWACS

The Airborne Warning and Control System aircraft is the most advanced radar plane in the world, which is no doubt why NATO employs them

Boeing Model 40

Flying between Chicago and San Francisco, Boeing's first commercial plane carried 1,200 pounds of mail plus two passengers

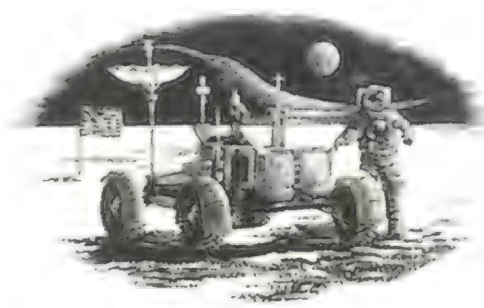


Boeing Clipper

50,000 parts added up to majestic flying boats that crossed the Atlantic to Europe and Pacific to Hawaii, transporting presidents and kings, GIs and movie stars

Boeing Minuteman

Nicknamed the "Instant Missile," the Minuteman ICBM system has been our nation's primary deterrent to nuclear aggression for 30 years



Boeing Lunar Roving Vehicle

The LRV performed flawlessly as part of the Apollo 15, 16 & 17 missions, causing Astronaut Gene Cernan to exclaim, "It was the finest machine I've ever had the pleasure to drive"

License to Launch

5, 4, 3, 2, 1…wait a minute. Have you completed all your paperwork?

by Martin Morse Wooster

Illustrations by Richard A. Goldberg

After years of research and development and buckets of blood, sweat, and tears, your up-and-coming company, Rockets 'R' Us, is ready to debut its brand-new Blastoff!™ booster. Use of the launch site has been negotiated, the payload has been mated to the launch vehicle, and a volley of press releases awaits firing from corporate headquarters. But if you don't have a launch license—the government's blessing, in paperwork, to hurl an object into space from U.S. shores—you're not going anywhere.

For orbital entrepreneurs, the road to space doesn't begin at Cape Canaveral, White Sands Missile Range, or NASA headquarters. The first step of a commercial launch's long journey is taken at the fifth floor of the Department of Transportation headquarters in Washington, D.C. Wedged between a Pipeline Safety office and the Saint Lawrence Seaway Development Corporation, is the Office of Commercial Space Trans-

portation, regulator of private industry in space.

"We want to make commercial space activity a routine part of life," says OCST director Stephanie Lee-Miller, who hopes her agency will be considered as important—and, perhaps, as mundane—as the agencies that oversee the nation's highways, cargo ships, and air traffic. In a country where, for most of its citizens, space activity means billion-dollar space shuttles and top-secret spy satellites, that may seem a wildly futuristic notion. The field of the commercial launch industry is, in fact, only a decade old. When, in September 1981, Space Services Incorporated of Houston wanted to obtain government approval for the suborbital launch of its little Conestoga booster, it asked NASA for advice. NASA's general counsel recommended that SSI talk to the state department, the Federal Aviation Administration, and the defense department, for starters. In most cases, says Charlie Chafer, who headed SSI's licensing effort, federal agencies were simply confused. "No one was saying, 'We're not going to let you do this,' " he recalls. "We got a lot of 'We don't know what the rules are' answers instead."

Ultimately, SSI only had to obtain permission from the FAA, NASA, and the Department of State before launching a dummy payload from Galveston, Texas, to an altitude of 192 miles in September 1982. (In addition, the Bureau of Alcohol, Tobacco, and Firearms licensed SSI to import "weapons"—the German calibrating rockets SSI used to fine-tune its radar.) But it was not until the weekend before the launch that the Department of State's Office of Munitions Control declared that SSI had a license to "export" the Conestoga to space. "We were risking a lot of money—up to a million dollars—on whether or not I had gotten all the permissions done in time," Chafer says.

After SSI's launch, more agencies jumped on the licensing bandwagon. By 1983, a dozen federal agencies declared that they needed to be consulted before a private firm could launch so much as a sounding rocket. The state department insisted that a prospective launcher must obtain a "license for temporary export of unclassified defense articles." The FAA wanted to ensure that a rocket would not bring down an airplane. The Federal Communications Commission had to allot radio frequencies and review radio operator licenses. The Materials Transportation Bureau regulated the shipment of rocket fuel to the launch site. The rest of the parade consisted of the Office of the Secretary of Defense, NASA, the Air Force, the Navy, the Coast Guard, the North American Aerospace Defense Command, the Office of the Secretary of Transportation, and the Bureau of Motor Carrier Safety.

The victim of all this red tape was the commercial launch industry. Clearly, one agency had to be in charge, and it couldn't be NASA, whose shuttle was the chief competitor of private enterprise in space. Should commercial space regulation fall under the aegis of the government's promotion of business and be placed in the commerce department? Or should the new agency be housed with the air and road regulators in the transportation department? Secretary of Commerce Malcolm Baldridge and transportation secretary Elizabeth Dole went to battle.

Dole eventually won, persuading President Reagan to establish an Office of Commercial Space Transportation in the DOT. The following year, 1984, Congress passed the Commercial Space Launch Act, defining the new office's scope and functions: it would certify that the launch vehicle performed safely, was environmentally benign, and did not carry a payload that would violate U.S. national security or foreign policy interests. "Blue skies, not red tape," Reagan proclaimed during the signing ceremony, a tidy phrase that became the new office's motto. But there were still a few sticky issues to contend with.

NASA remained a formidable competitor to private interests. Why would a satellite builder pay Martin Marietta or McDonnell Douglas $60 million to launch a satellite when NASA would do it for $15 million? Then, in January 1986, the *Challenger* explosion rewrote the rules of the high-stakes game. Reagan banned most of private industry from hitching a ride on the shuttle. A corporation that needed a telecommunications satellite launched could turn only to the European consortium Ariane—standing room only—or, depending on which way the political winds were blowing at the moment, to the People's Republic of China.

Another hurdle was the burgeoning problem of liability. Because the industry was still in its infancy, the risks of a launch were largely undocumented. The Air Force assumed that this meant the dangers of commercial spaceflight were unlimited—what Norman Bowles, OCST's associate director for licensing and programs, calls "the 'what happens if a rocket enters Miami Stadium during a convention of trial lawyers' scenario." In 1987, Richard Brackeen, then president of Martin Marietta Commercial Titan Systems, said the insurance requirements for the company's contracts to launch communications satellites from Cape Canaveral in Florida added "a few million dollars a launch" to the cost of doing business.

"Blue skies, not red tape," Reagan proclaimed during the signing ceremony. But there were still a few sticky issues to contend with.

The undefined nature of the risks of spaceflight presented a second problem. Suppose that your debuting Blastoff!™ dribbled a tiny amount of hydrazine and nitrogen tetroxide on the launch site and was eventually cited as contributing to an environmental hazard. Even if Rockets 'R' Us had conducted only three launches for every 100 the Air Force conducted at the same site with the same fuel, your company, under the doctrine of "joint and several liability," could lose all its assets, since the government can rarely be sued and private companies supposedly have the deepest pockets of any potential defendant. And an enterprising lawyer could then sue your insurance company for everything *it* owned. "You could envision

a situation where all the Lloyd's of London partners who underwrote that activity could be drained of all their assets," says James Bennett, vice president of the American Rocket Company in Camarillo, California.

In May 1988, the DOT issued its first report defining launch hazards. Using data that NASA and the defense department had compiled in the 1960s, the agency determined that a rocket run amok was far less threatening than more common industrial operations. The fuel used in a three-stage Delta, for example, contains 1.5 billion British thermal units of energy, roughly the same amount as a tank truck carrying 15,000 gallons of gas. A rail tank car loaded with propane holds 2.8 billion BTUs; a fully loaded jumbo jet, 7.3 billion. Thus insurance companies could issue policies based on known, limited risks.

That year, Congress amended the Commercial Space Launch Act. Launchers were now required to purchase only the insurance for the maximum probable loss a rocket could cause, as determined by the OCST and the launcher. The government agreed to pay for all further damages. Thus Congress not only limited the risks for the industry, it also substantially reduced the cost of doing business.

With insurance now available, prospective launchers gradually began to fulfill the licensing requirements. In 1988 the OCST issued licenses to Conatec (whose launch is still on hold) and McDonnell Douglas, and on March 29, 1989, SSI conducted the first U.S. commercial launch (see Soundings, June/July 1989), firing a two-stage suborbital rocket carrying materials processing experiments from the White Sands range in New Mexico. Five months later McDonnell Douglas executed the first commercial orbital launch, lofting a Delta rocket carrying a British TV satellite from Cape Canaveral.

Since then the commercial launch industry has grown like Topsy. In 1989 three commercial payloads were launched; in 1990, 11; and for this year, 17 are scheduled. As private launches become more routine, the paper trail that precedes them becomes more innovative.

Fortunately for space entrepreneurs, there are no forms with eye-straining print and "check here" boxes to fill out. "We don't want to tell companies that they have to conform to a form and follow A, B, and C to get a license if their rocket doesn't have a B," says OCST's Bowles, a youthful 18-year veteran of the DOT whose succinct comments are sporadically interrupted by freight trains groaning past his window. Applicants are instead asked for a summary stating who they are, where they—and their lawyers—are located, the launch range they plan to use, the type of rocket they have, and the number of launches anticipated. Payload content must be described, including any material "that could pose a unique hazard to the public." (Propellants are not considered "uniquely hazardous" unless a rocket is being fired from a brand-new site.)

Licensing can be wrapped up in as little as four weeks—or may take as long as eight months, if new sites or technology come into play. Once an application is received, the OCST conducts a safety review. All applicants must supply a considerable amount of documentation on the safety of their mission, including the training qualifications and experience of everyone involved in ensuring safety.

While it helps if an applicant uses existing technologies or plans to launch from an OCST-sanctioned site (Vandenberg and Patrick Air Force Bases in California and Florida, NASA's Wallops Island in Virginia, the Army's White Sands, and the Navy's Barking Sands in Hawaii), the office won't automatically disqualify a rocket or launch site simply because it is untried. Enterprising state agencies are following Florida's lead by considering constructing civil ranges in Mississippi, Alaska, and Hawaii. "This is a brand-new industry, so we will address each technology on its own merits," says Bowles. "If you want to stifle an industry, you will be very prescriptive in what you will allow." American Rocket's Bennett sees the OCST as one of the few regulatory agencies that does not punish innovation. "People who have new ideas aren't ruled out of bounds," he says. "You go to the DOT and they don't say, 'The model has to be X.' When we brought a hybrid rocket to them, they didn't scream or become hysterical."

After the safety of an applicant's vehicle has been established, the OCST sends the mission plan to NASA, the Department of Commerce, the FCC, and the state and defense departments for comments. Only the latter two can blackball an application, and then only if State feels that the mission is contrary to U.S. foreign policy interests or Defense deems it a threat to national security.

As far as the actual payload goes, the

OCST evaluates only the risk of environmental damage, not the payload's purpose. Consider the case of Celestis, to date the licensing office's most unusual applicant.

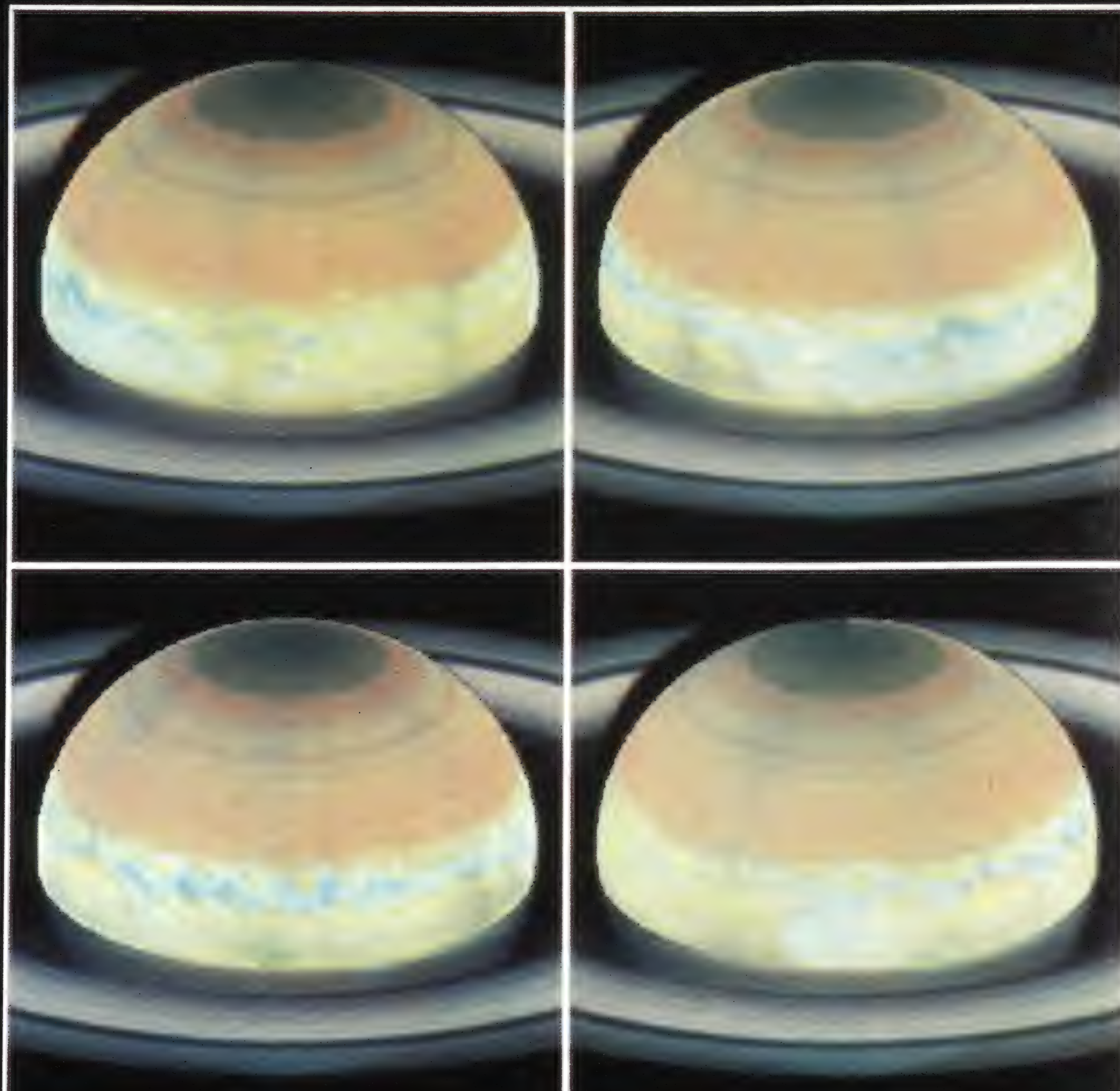
In 1986 a group of Florida investors known as the Celestis Group approached SSI with a request for a launch service: orbit a satellite containing the cremated remains of 10,000 people. Celestis planned to reduce human remains to about an ounce per individual, pack the powder into a gold-plated capsule the size of a lipstick tube, and charge funeral directors $3,900 per customer for a space in an orbiting mausoleum.

The OCST took SSI's application in stride—Celestis passed both safety and mission reviews. But before a license was granted, the state of Florida charged that Celestis planned to operate a cemetery without a license, and that such a license could not be granted because the operation lacked features that the state required, like roads leading to the gravesites. Rather than battle the regulators, Celestis abandoned the project. "I think what happened is they said, 'Ah, never mind,' " says Charlie Chafer, then SSI's Washington liaison.

The licensing process is constantly evolving. Last February the OCST issued to General Dynamics its first Launch Operators License, which allows a company to conduct a series of launches with the same equipment and similar payloads over an extended period, rather than having to apply for a new license for each launch. ("You can imagine what might happen if American Airlines had to obtain a license for each of its flights," says Bowles.) McDonnell Douglas and Orbital Sciences, the industry's rising star, recently won similar licenses. In addition, the licensing office hopes this year to issue the first joint-venture license, permitting SSI (now EER Systems) and Space Industries, another Texas-based space engineering firm, to launch an orbital microgravity lab.

To date, no one has raised the question of human payloads, but if someone does, Lee-Miller would do what most bureaucrats do in an unprecedented situation: pass it on to her superiors. "We'll have to be specifically authorized by Congress before we approve a launch of human beings," she says.

But even without human payloads, commercial spaceflight is being transformed into a pedestrian enterprise, thanks to the OCST. American Rocket's Bennett says that by establishing levels of risk and determining licensing procedures, the office has replaced risk-avoiding policies with the "predictable regulatory environment" necessary for the fledgling commercial launch industry to spread its wings. Rockets 'R' Us will have to be pretty sharp, though, to get its license. The OCST does not issue learner's permits.



Forecast: **Liquid Helium Showers, Temperatures 290 Below Zero**

by Mark Washburn

Disgruntled with the weather here on Earth? Count your blessings. It's guaranteed to be better than it is anywhere else in the solar system.

A rare, mid-latitude storm, as seen last November by the Hubble Space Telescope, completely encircles Saturn. Though such enormous storms seem exotic by Earthly standards, understanding them may help us understand the weather of our home planet as well.

As I write this, it is raining here in eastern Massachusetts. Elsewhere in the solar system, other stuff is falling from other skies.

On Venus, there may be a light drizzle of sulfuric acid droplets, descending toward the hellish surface from a high-altitude haze layer. Near the polar caps of Mars, a gentle carbon dioxide snow may be falling. It's snowing sulfur on Jupiter's moon Io, while high in the turbulent atmosphere of Jupiter, frozen crystals of ammonia are precipitating out of the uppermost clouds. A little lower, where the atmosphere is warmer, it's snowing ammonium hydrosulfide. Lower still, there may be scattered showers of good old H_2O. On Saturn—or more precisely, *in* Saturn—the rain may consist of drops of liquid helium. Beneath the dense clouds blanketing Saturn's moon Titan, gobs of hydrocarbon goo may be piling up on the surface in drifts hundreds of feet high. And in Louisiana, according to the Weather Channel, it's raining cats and dogs.

We have three general methods for finding out these things: direct sensing, remote sensing, and modeling. Direct sensing means that I go outside, get wet, and conclude that it's raining. Remote sensing lets me stay dry while I watch the rain through my window. Or, if I were in a closed room, I could use other types of remote sensing to learn about conditions outside, although I would have slightly less confidence in what they told me. For example, if my knees ache, I can be fairly sure it's going to rain. And there's always the Weather Channel.

Modeling is more subtle and less accurate. A representation of the universe as we understand it, a model can rely on either historical experience or numerical formulas portraying the laws of physics. My historical model says: "I washed the car yesterday and I want to play golf this afternoon; therefore, it must be raining." If I want to quantify my model, I can turn to the almanac and find figures for the average monthly rainfall at this time of year, then calculate the likelihood that it is raining today. These seat-of-the-pants models have a basis in climatology, the study of long-term, prevailing atmospheric conditions, as opposed to the day-to-day changes in the atmosphere we know as weather.

If I were to create a model based on physical laws I would need a larger computer and several more years of education. Computer modeling, augmented by laboratory simulations, can give scientists a detailed portrait of likely conditions in inaccessible locations. But nature tends to be more subtle (and more devious) than even the most sophisticated models.

While those three methods are easily and widely applicable on Earth, the one most valuable for learning about extraterrestrial weather has been re-

mote sensing. Techniques include old-fashioned observations at the eyepiece of an optical telescope, the use of radio telescopes to determine the composition of a planet's clouds and to probe the planet itself, collecting data with Earth-orbiting satellites (including the powerful but flawed Hubble Space Telescope), and observations made by instruments aboard interplanetary spacecraft such as the Pioneers and Voyagers.

Direct sensing of weather on other planets, albeit with robots standing in for humans, has been limited to nearby Mars and Venus. (Mercury, the planet closest to the sun, has virtually no atmosphere and thus little in the way of weather.) The other planets are much harder to reach. However, if all goes well with the Galileo probe, launched by space shuttle in October 1989, its atmospheric entry probe should descend through the upper cloud decks of Jupiter sometime in 1995. There it will radio back *in situ* data for perhaps an hour until it is finally fried or crushed by the intense heat and pressure in the lower atmosphere.

Of all the planets, Venus and Mars have the most to tell us about our own atmosphere, and they've already played an important role in research on subjects ranging from global warming and ozone depletion to nuclear winter. Studies revealing that global dust storms on Mars caused temperatures near the surface to drop, for example, led directly to formation of the theory of nuclear winter, which predicts that particles in the air released by the fires of nuclear war could dangerously lower Earth's surface temperatures.

Venus has been inspected by probes dropped into its atmosphere by Pioneer Venus 2 and a flock of Soviet Venera landers and balloons (see "Balloons Over Venus," June/July 1988). They've revealed that in a sense the planet has no real weather—the oppressive climate simply overwhelms day-to-day fluctuations. The surface temperature of about 900 degrees Fahrenheit varies little from day to night or year to year. The atmospheric pressure at the surface is about 90 bars (Earth's is about 1 bar), or enough to support about 2,700 inches of mercury in a sufficiently large barometer. Wind speeds at the surface

Radar telescopes are but one of the many tools of the interplanetary weatherman.

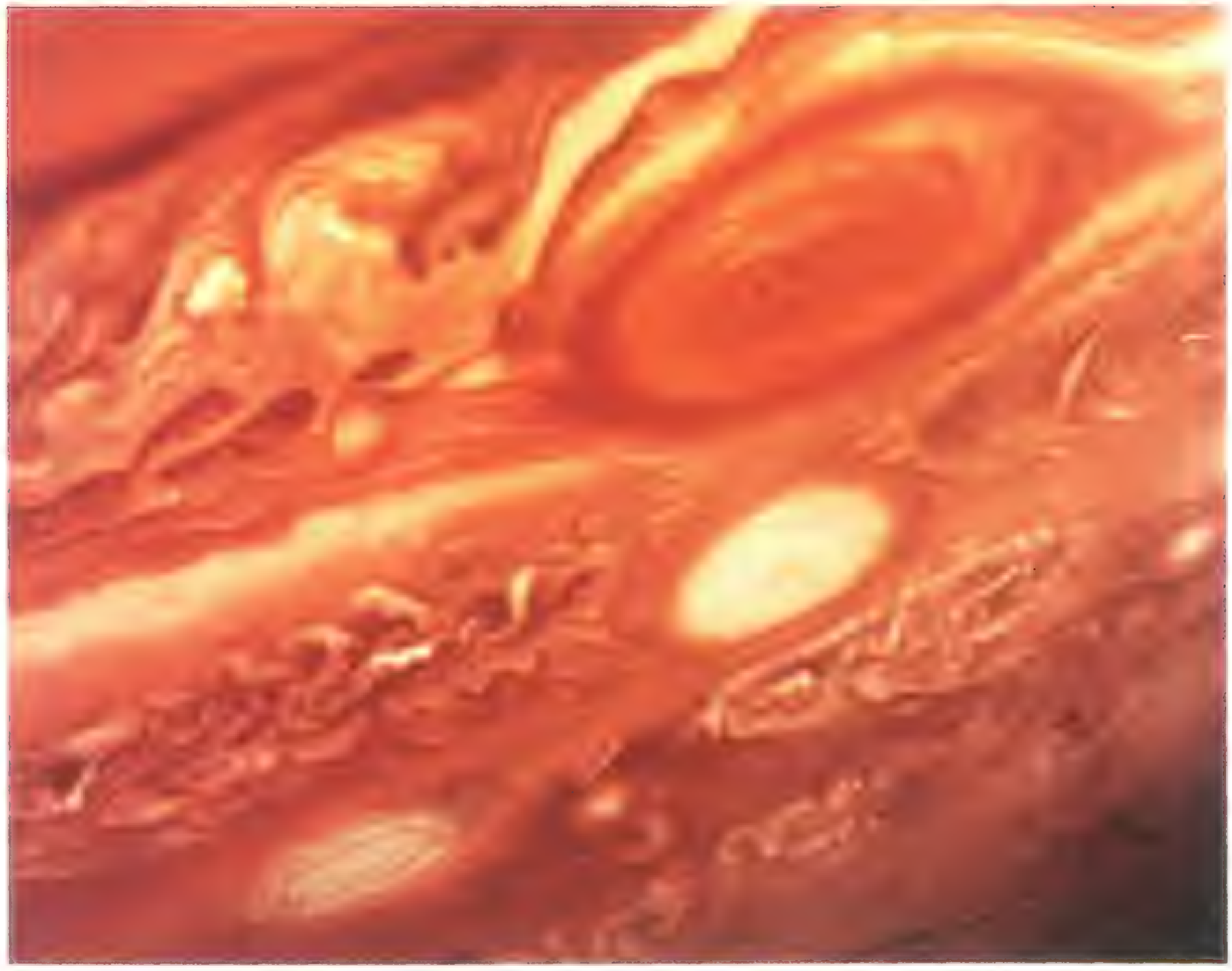
ROGER RESSMEYER/STARLIGHT

are only about 4.5 mph (versus a terrestrial average of about 22 mph), but because of the density of the atmosphere, those winds are some 10 to 15 times stronger than Earthly breezes.

Mars, in contrast, has recognizable (and generally predictable) weather patterns. When the Viking 1 lander touched down in the Chryse Basin in the Martian northern hemisphere on July 20, 1976, instruments on its meteorology boom began collecting data on temperature, pressure, wind speed, and wind direction. The next day, Viking meteorology team leader Seymour Hess of the University of Washington delivered a Martian weather report to the press. Just after dawn at Chryse, the surface temperature was –122 degrees, rising to about –20 degrees by mid-afternoon. Daytime pressure held steady at 7.7 millibars, less than one percent of Earth's pressure at sea level. Winds, gusting up to 14.6 mph, were from the east, shifting to southwesterly after midnight. Readings for the next two days (or sols, as the 24-hour, 37-minute Martian days are known) were virtually identical. "If Viking has accomplished nothing else," Hess joked, "it has converted meteorology to a reproducible science."

Actually, the bland weather was no surprise: unlike Earth, Mars has no oceans to complicate air circulation patterns. The repeating winds were simply a Martian version of the familiar terrestrial phenomenon known as "valley winds." Each night, the cold, dense air in the Tharsis highlands, southwest of Chryse, simply slid downhill into the basin. The process repeated itself throughout most of summer in the Martian northern hemisphere, and Viking dutifully recorded it until the probe's wind quadrant sensor failed. By then the glitch didn't even matter; Viking engineers had learned to determine wind direction simply by noting the difference in cooling rates on opposite sides of the spacecraft, confirming once again the truth of Bob Dylan's observation that you don't need a weatherman to know which way the wind blows.

Mars' most dramatic meteorological phenomenon is a product of these winds. During summer in the southern hemisphere, huge clouds of dust sometimes rise from the surface and spread to blanket the entire planet. Because Mars has



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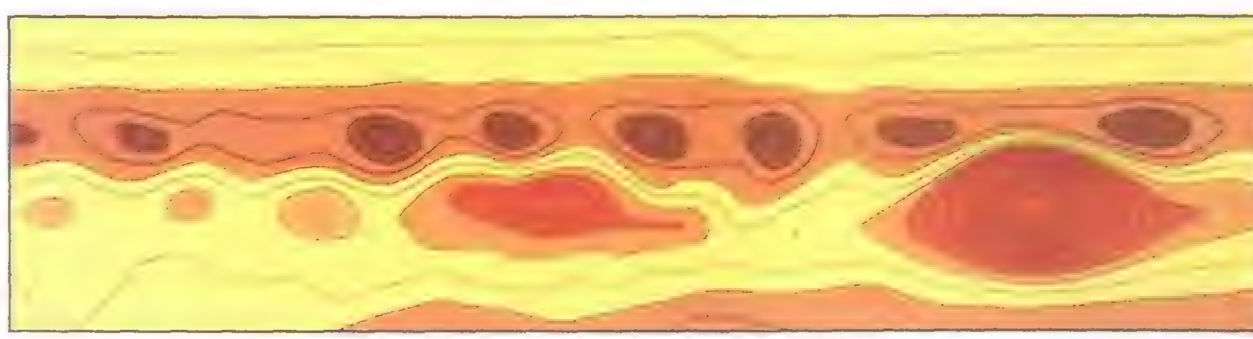
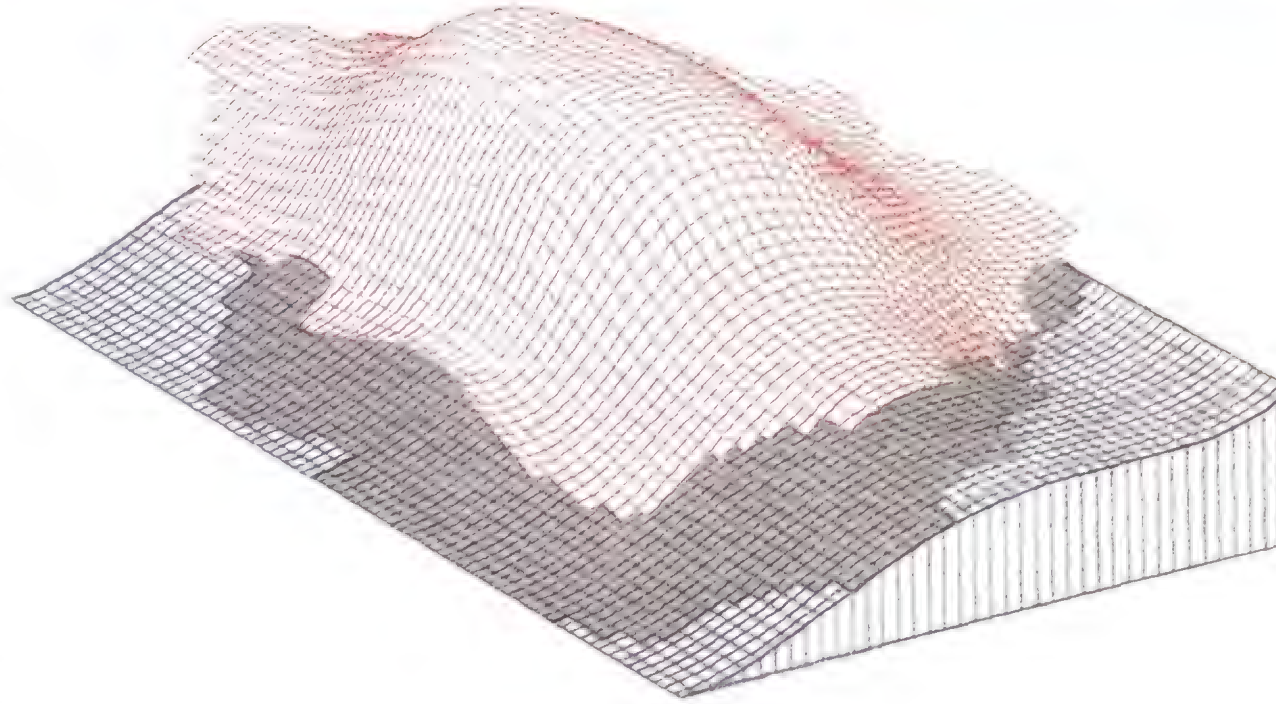


GARETH WILLIAMS



TIMOTHY DOWLING

Observed for over three centuries, Jupiter's Great Red Spot (top) has been a fascinating puzzle to planetary scientists for nearly as long. Computer models (center) and research in fluid dynamics have shown that many small-scale disturbances can give rise to a single, long-lived one like the GRS. The turbulence is likely caused by the combination of heat from deep inside the planet rising through its layers of atmosphere and warmth from the sun entering the atmosphere, then ascending back to the surface. A topographical model of the giant storm (bottom) assumes it to be a high-pressure system and shows it swelling high above surrounding cloudtops.

a highly elliptical orbit, by the time summer arrives in the southern hemisphere, the planet is about 25 million miles nearer the sun than it was during the northern summer. As a consequence, during the southern summer the planet receives about 40 percent more solar energy, which drives winds of up to a few hundred miles per hour. With Mars' low atmospheric pressure, however, these winds alone would probably not be able to create enough shear stress on the surface to lift dust particles skyward. According to Ralph Kahn, a planetary scientist at the Jet Propulsion Laboratory in Pasadena, California, some mixture of other, still unknown factors must be enhancing the flow of winds across the surface.

One thing that definitely wouldn't be a factor is rain, something Mars hasn't seen in several billion years, though one form of water precipitation may still exist. Kahn says that a small amount of tiny ice particles probably precipitates in Mars' northern hemisphere during its cool season. This phenomenon, known as "clear air" precipitation because of the lack of heavy clouds, has been observed in the Antarctic under similar conditions. The total amount of ice precipitated on Mars, however, would stack up to a layer only a few thousandths of an inch deep. More substantial snows of carbon dioxide crystals (that is, dry ice) may occur near the Martian polar caps, but no one can say for sure, says Kahn.

Locked in Mars' shifting sands and layered polar caps is a detailed history of weather and climate—a history not just of Mars but perhaps also of Earth. The drifting of continents and the pounding of waves have erased much of Earth's history, but on Mars most of the geologic record has been preserved. Evidence suggests that some three billion years ago the surface of Mars was covered by a large amount of liquid water. Current theory holds that Mars' atmosphere changed over those billions of years, perhaps due to the planet's gradual cooling, eventually lowering the surface pressure to the point where liquid water could not exist. Martian rocks and ice cores could provide invaluable data on how the planet's atmosphere developed, thereby illuminating the process on Earth as well.

Of particular interest is the exact timing of ice ages on Mars. Some possible contributing factors, such as passage through occasional interstellar dust clouds and variations in orbit and in the sun's output, are shared by Earth and Mars. Others, such as continental drift, are found only on our planet. So finding proof of simultaneous ice ages on the two worlds could lead researchers closer to determining the true causes of such catastrophic global change.

Unlike the "terrestrial" worlds of Venus, Earth, and Mars, which are basically lumps of rock with thin atmospheric shells, the planets of the outer solar system (except for tiny, rock-like Pluto) are huge, lightweight balls of hydrogen and helium collectively known as gas giants. Something between stars that never switched on and terrestrial planets, the gas giants have relatively small solid cores surrounded by thick, massive atmospheres.

Chemically, the atmospheres of the gas giants are a much richer soup than Earth's. We have only one cloud-forming constituent—water—but the gas giants have several, each of which condenses at a different temperature. As the planets' cores radiate the heat left over from their formation, layer upon layer of chemically different clouds form around them. The weather out there can be summed up in one word: *windy.*

Immense storms whirl through the atmospheres of the gas giants. The Great Red Spot of Jupiter is an angry red oval storm system three times the diameter of Earth, and it has been observed for over three centuries. "Normally a storm is part of weather, but on Jupiter storms are part of the climate," says Andrew Ingersoll, a planetary scientist at Caltech and a member of the Voyager imaging team. Similar ovals have been seen in the atmospheres of Saturn, Uranus, and Neptune; the latter's Great Dark Spot rivals the Great Red Spot as the most spectacular storm in the solar system.

Measuring the wind of the gas giants' atmospheres is a difficult business because the planets lack a solid outer surface that could be used as a reference point. Traditionally, astronomers had to track large atmospheric features from one planetary rotation to the next and attempt to measure their movements over time. (A newer method of wind measurement—see "The Light of a Distant Wind," p. 65—had yet to be applied to gas giants.)

When the Voyagers arrived at the planets of the outer solar system, they followed a similar procedure but on a dramatically different scale. Instead of tracking Earth-sized storm systems, Voyager scientists were able to follow individual cloud features no bigger than, say, Texas. The results were startling. After Voyager 1's first look at the clouds

Travelers' Advisories

Venus Today: hot and cloudy. Tomorrow: hot and cloudy. Surface temperatures average around 900° F, with light winds and pressure holding steady at 90 bars. Chance of sulfuric acid rain.

Earth Gentle winds and mean surface temperature of 72° F; consult local forecasts regarding extremes of wind, temperature, and precipitation. Long-term trend: warming climate, ozone depletion, atmospheric pollution. Advice: See it now.

Mars Bitterly cold in polar and nighttime equatorial regions, with

of Jupiter, Bradford Smith, an astronomer at the University of Arizona and leader of the Voyager imaging team, commented glumly, "The existing atmospheric circulation models have all been shot to hell by Voyager."

Voyager revealed that Jupiter has far more widespread turbulence than had previously been assumed, making the Great Red Spot's long lifespan all the more surprising. Scientists had thought a relative calm would surround such large storms, but now they believe that the many smaller storm systems may be feeding the larger ones and keeping them going.

The oval storms on the gas giants are often compared with Earthly hurricanes, but the analogy, says Ingersoll, "is not too good." The Great Red Spot is at best a distant cousin of the storms that rake the oceans of our own planet. The gas giants have no visible oceans to give birth to hurricanes, for one thing; the energy source for these storms seems to be heat from the lower layers of the atmosphere. The storms probably also draw energy from the 300-mph jet streams that whistle through the horizontal stripes of Jupiter's "belts and zones."

For all their differences, Jupiter's storms do bear some resemblance to our hurricanes. Hurricanes in Earth's northern hemisphere rotate counterclockwise near the surface but clockwise at the cloudtops. Though its behavior can be observed only at the cloudtops, the same seems to be true of the Great Red Spot. On the other hand, terrestrial hurricanes do not last for centuries. Nor are they red.

carbon dioxide flurries possible. Daytime equatorial temperatures may rise to 70° F, but absence of ozone layer makes tanning inadvisable. Seasonal dust storms likely.

Jupiter Upper atmosphere temperatures average –250° F; lower levels are warmer. Narrow comfort zone in water-cloud region, but the pressure there is five times Earth norm. Large storm systems likely for next century, with winds over 300 mph.

Io Satellite of Jupiter continues its spectacular volcanic eruptions. Thin atmosphere of volcanic gases swept by 600-mph winds. Sulfur and sulfur dioxide snows blanket the surface.

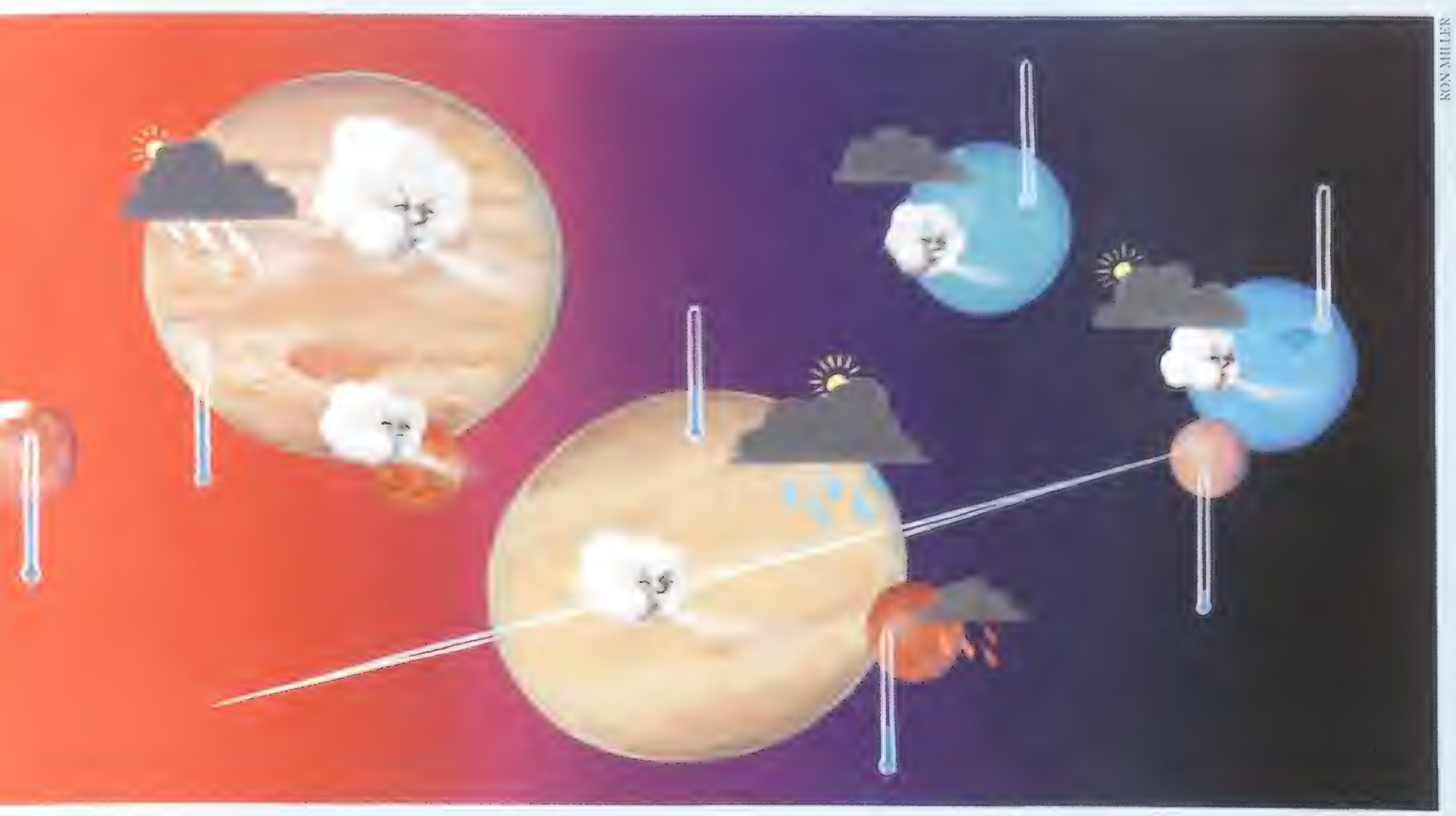
Saturn Temperatures in upper atmosphere average –290° F, with gradual warming at lower elevations. Liquid helium rain probable in high-pressure interior. Scattered atmospheric storm systems, with gusts up to 1,000 mph.

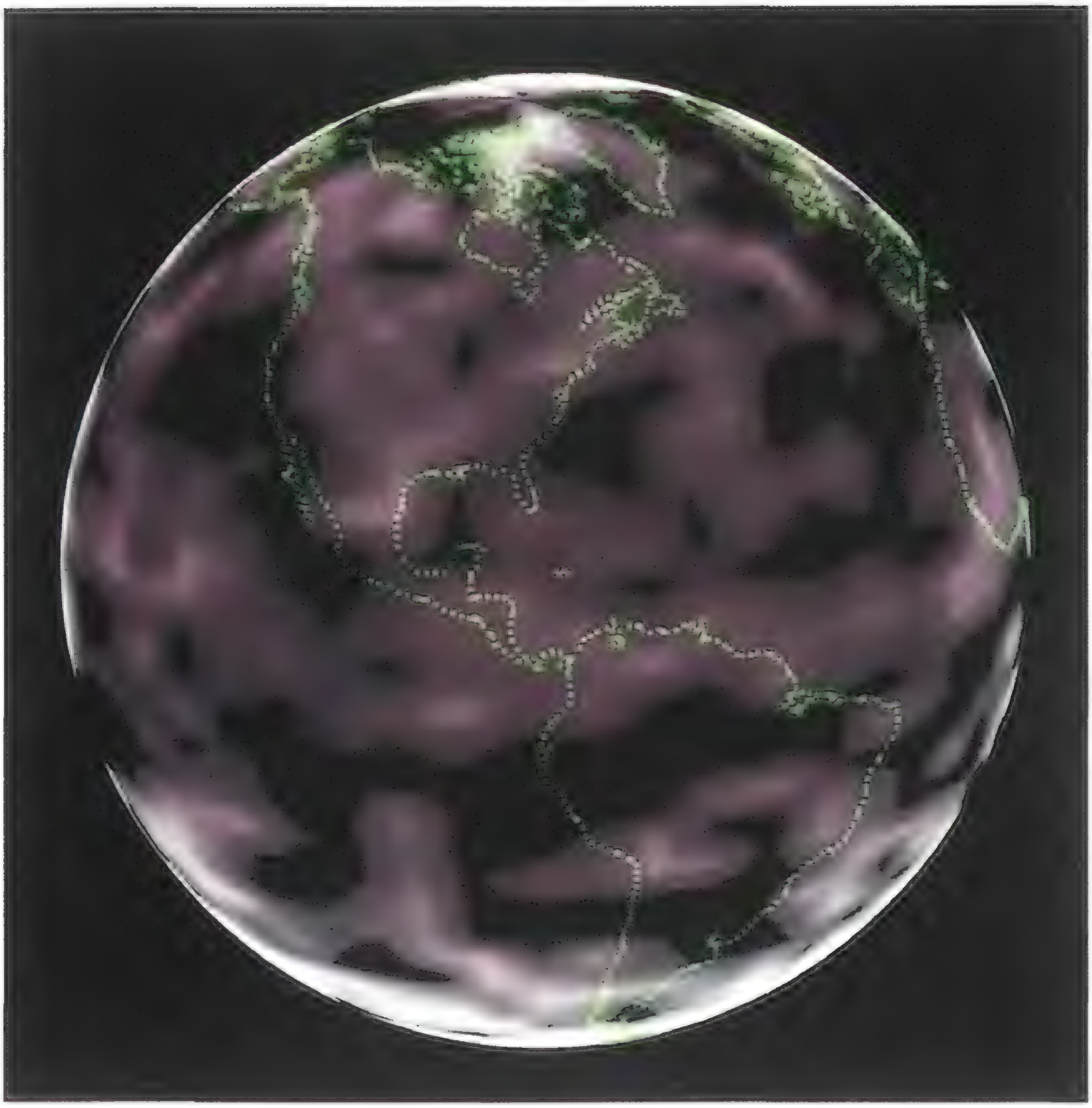
Titan Hazy, cloudy, and cold. Beneath its clouds, this large Saturnian satellite has a surface temperature of –290° F. Rains of complex hydrocarbons likely, with scattered showers of ethane or methane possible. Winds to 200 mph.

Uranus High hydrogen haze reduces visibility. Scattered storms possible in upper atmosphere, with average temperature of –350° F and wind speeds up to 400 mph.

Neptune Some fleecy, white "fair weather" clouds, but storm conditions prevailing in Great Dark Spot, with winds over 700 mph. Hydrocarbon rains in the lower atmosphere likely. Daytime high of –360° F.

Triton Winds of about 30 mph on this Neptune moon, producing dark plumes of nitrogen ice removed from surface by either geysers or "dust devils" similar to those in Earth's American Southwest. Surface is coldest on record, –400° F. Bring extra sweaters.





GARY GLATZMAIER/LOS ALAMOS

Computer models enable scientists to explore atmospheric phenomena by taking weather data and manipulating it along known parameters. This computer simulation of Earth reveals how water vapor and wind interact to form clouds. Just like real clouds, these will eventually produce "rain."

Astronomy, like meteorology, is one of the last scientific disciplines in which amateurs can still make an important contribution, and they scored last September by reporting a great new storm system bubbling up from Saturn's lower atmosphere about five degrees north of the equator. Saturn had been hanging low in the evening sky, where our atmosphere is turbulent and the viewing time limited—a scenario not especially attractive to professionals but admirably timed for the after-dinner amateur observer. Nevertheless, by October the professionals moved to the forefront, and soon the Hubble Space Telescope got into the act.

Despite problems with the Hubble's expensive mirror, astronomers have been able to coax some excellent data out of the system and have begun periodic observations of the outer planets. The Hubble's best pictures of Jupiter are no better than images Voyager captured when it was still 16 days away from the planet, but Voyager was a one-shot flyby, whereas the Hubble can monitor the changing faces of the gas giants once or twice a year. Still, that isn't quite enough for astronomers like Reta Beebe of New Mexico State University: "Planetary people will do anything they can for more time on the Hubble. We aren't even shameful about it," she admits.

Images from the Hubble and from ground-based telescopes will enable astronomers to analyze the Saturnian storm and, perhaps, explain it. That won't be easy, because it seems to be the third in a series of storms arising at that latitude every 57 years, or just under once every two Saturnian years. If the storms erupted every year, they would be explainable as a seasonal phenomenon, but every *other* year? "It just doesn't quite make sense," says Ingersoll. He contrasts the storm with a volcanic eruption. Somewhere in the interior, pressure gradually builds up; "It waits and waits, and then goes *blaaast!*" But volcanic eruptions are restrained by miles of solid rock on Earth; on gaseous Saturn, what holds back the "bubble" for 57 years?

In the absence of final answers to such questions, scientists can still take pleasure in the observations themselves. Reta Beebe enjoys talking about the atmospheric wave patterns she sees not only on Jupiter and Saturn but on Earth as well. "Out here in southern New Mexico you can walk out and see lovely bands of clouds parallel to the mountains, extending eastward for miles," she says. In New Mexico, the waves are created when air moving eastward rises to flow over the mountains. With the gas giants, the mechanisms behind atmospheric storms and waves remain unclear.

The answers may finally come not from observations but from computer models. In the late 1970s Gareth Williams of Princeton University created a remarkably accurate-looking simulation of the belts, zones, jets, and ovals of the atmosphere of Jupiter using a computer model designed for Earth's atmosphere. Since the model didn't take into account anything under the surface layer of Jupiter's atmosphere, however, some scientists suspected that Williams' model reproduced the planet's appearance but not its workings.

A new computer model being developed by physicist Gary Glatzmaier of Los Alamos National Laboratory in New Mexico looks deeper into Jupiter's interior. Unlike Williams' model, Glatzmaier's simulation models the flow of energy and matter far beneath the swirling cloudtops. "I don't see any reason why [Jupiter's atmospheric flow] would not involve the interior," says Glatzmaier. "It's hard for me to envision a giant planet with winds only at the surface." His model runs on a Cray-YMP supercomputer but still takes hundreds of hours to crunch the necessary numbers. He hopes that by this autumn he will have a finished model, which he will be able to demonstrate as a movie showing Jupiter's atmosphere in three dimensions. "The more I work on it, the more I find how difficult it is, and I see why no one else has worked on it," he says.

In a sense, modeling is simply a mat-

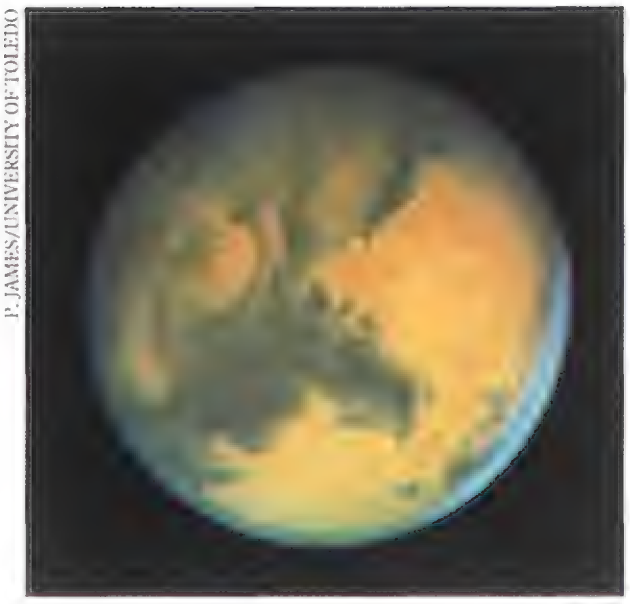
ter of finding the right scale. Millions of calculations describing the physics of fluid flow and heat transfer must be performed for each time step—what Glatzmaier calls a "snapshot"—at every point on the modeling grid. A model of North America with monthly time steps and a grid scale of 500 miles between points would be easy to calculate but would tell little that was new. Time steps of a minute with a grid scale of 10 feet would produce a wonderfully detailed model—after about 1,000 years of computer time. Glatzmaier's initial version of the Jupiter model looked good but the time steps proved too small for practicality, and he was forced to try again using longer time steps. It is, he says, "a very challenging numerical problem."

Glatzmaier is a leading example of a new breed of scientists who emphasize the importance of a cross-disciplinary approach in solving the mysteries of planets, including Earth. Starting as an astrophysicist, Glatzmaier modeled the interior of the sun, then tackled a model of the fluid interior of Earth's mantle. When he got interested in Earth's atmosphere, he began tinkering with models created at the U.S. government's National Center for Atmospheric Research. His model of Jupiter, involving details of hydrodynamics, thermodynamics, and magnetohydrodynamics, will incorporate lessons learned from his previous diverse efforts.

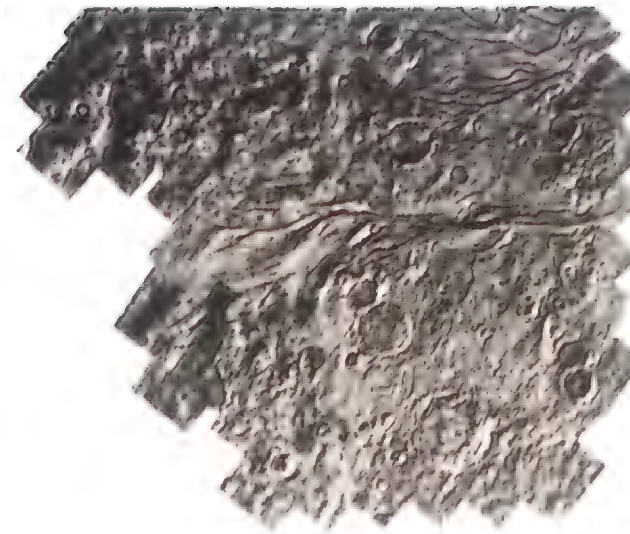
Weather on Jupiter is interesting; weather on Earth is a matter of life and death. Can multi-planet, multi-discipline studies really teach us anything important about the planet that matters the most? "That's usually an argument made to get funding," laughs Glatzmaier, "but in my case I can honestly say that. You bring a little something along—the cross-fertilization has helped me a lot."

It may be too soon to say that understanding storms on Jupiter may ultimately help us predict them on Earth, but don't bet against it. JPL's Ralph Kahn notes that some conservative scientists tend to denigrate multi-disciplinary approaches to difficult problems, typically referring to such efforts as "fishing trips." But, Kahn points out, "If you don't go fishing, you're never going to catch the big one."

P. JAMES/UNIVERSITY OF TOLEDO



NASA/MICHAEL H. CARR



Frigid and inhospitable, the Mars we know today is a far cry from the vibrant world scientists once imagined. The planet's low surface pressure precludes the existence of liquid water on its surface. But geological evidence (right) indicates that Mars was a very different place several billion years ago. Then the planet may have been covered by great floods. Mars' polar caps still harbor some frozen water (left), along with large amounts of dry ice.

The Light of a Distant Wind

How do you measure the velocities of winds on a planet millions of miles away? "With great difficulty," the punchline might go. But it can be done.

For astronomers using Earth-based telescopes, the most accurate method involves gathering infrared light emitted by molecules in the planet's atmosphere and comparing it at the telescope with infrared emissions from the same kind of molecules generated by a special laser inside an instrument known as an infrared heterodyne spectrometer. After factoring out differences in the emission's frequencies caused by differences between the motions of Earth and the planet under study, astronomers can attribute any remaining frequency shift to the planet's winds.

NASA/AMES RESEARCH CENTER

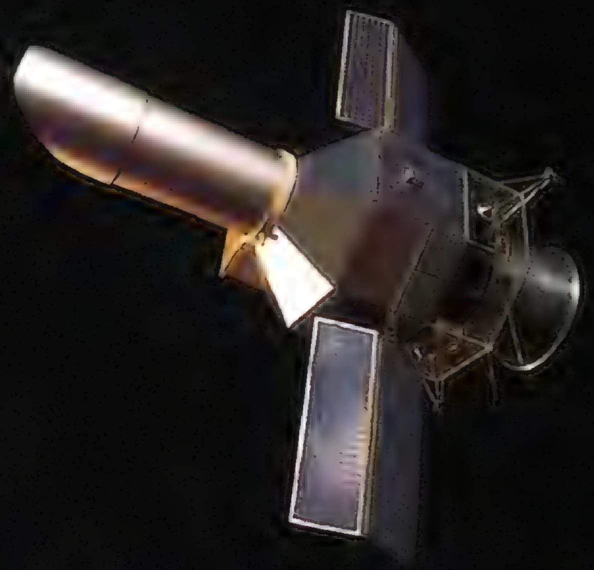
There is one catch: temperature changes can cause the laser's housing to expand or contract slightly, which changes the emission's frequency and makes the laser unreliable as a standard for comparison. Even a change as tiny as a millionth of a meter—0.00004 inch—in the laser cavity could throw wind measurements off by around 500 mph. If you're trying to measure the winds on Venus (below) to within two mph, as Jeffrey J. Goldstein of the National Air and Space Museum's laboratory for astrophysics is doing, "a one-millionth-of-a-meter change in the laser is terribly, terribly large."

Consequently, Goldstein has developed a device to continuously recalibrate the laser so its emissions never deviate from their expected frequency. The result, a spectrometer of unprecedented stability, has proven so successful that its use is being expanded beyond Venus to include wind velocity measurements on Mars, Jupiter, Saturn, and Titan.

Aside from adding to our knowledge of weather on these bodies, the new information can be used to confirm the validity of computer models—all part of testing our basic understanding of the physics of weather.

—*Karen Jensen*


SATELLITE



Even the most well-adjusted satellites need a little extra guidance now and then. Henry Hoffman sees that they get it.

SAVIORS

by Frank Kuznik

On the walls of Henry Hoffman's office are two large white markerboards covered from frame to frame with numbers. "Henry never erases his blackboards," says Michael Femiano, who works in Hoffman's domain, the Satellite Guidance and Control Branch of the NASA Goddard Space Flight Center. Except for a telephone number in one corner, all the numbers on the boards quantify the wayward behavior of satellites in trouble and chart the patient, firm plans to get them back in line.

"The black grid in the center is for ST," Femiano says, referring to the Hubble Space Telescope. "ST has jitter problems. The blue and red is for GOES [Geostationary Operational Environmental Satellites]. Until recently, there was IUE stuff over here that was six years old." The "IUE stuff" represented an impromptu exercise in satellite control that made it possible for the International Ultraviolet Explorer, launched 13 years ago and still returning data, to survive an almost fatal mid-life crisis and go on to become the most productive astronomical satellite ever to orbit Earth. The IUE had lost a critical position-determining device, but Hoffman figured out how to point the telescope without it.

All of NASA's Earth-orbiting satellites are managed and monitored at the Goddard campus in Greenbelt, Maryland. Some of the satellites are monitored 24 hours a day, ensuring that their power-drawing solar arrays are oriented toward the sun, their communications antennas are pointing to Earth receivers and transmitters, and their scientific instruments are accurately targeted. Every satellite system depends on guidance and control.

"When there's a panic on a satellite, it's usually the control system," acknowledges Hoffman, who has led Goddard's guidance and control branch for 30 years. A spark plug at 65 with the air of an impish college professor, Hoffman oversees a team of 45 engineers who spend most of their time designing control systems for the spacecraft developed at Goddard. The rest of their time is devoted to troubleshooting—a process that usually begins when Hoffman gets a breathless phone call at home.

"I was doing my taxes just the other night when I got a call saying that TDRS 4 had lost an Earth sensor," he says, sitting in his office amid a jumble of graphs, charts, technical reports, and satellite models. "If I'm late, I've got a great excuse for the IRS."

TDRSS, the Tracking and Data Relay Satellite System, is a multi-satellite communications network—essentially a set of radio repeaters in the sky—that relays data and voice messages between other spacecraft and a ground station in New Mexico. The failure of the TDRS 4 Earth sensor, a scanner that keeps the satellite pointed properly, interrupted communication with the shuttle for about 90 minutes during the April *Atlantis* mission (see diagram, next page). A backup sensor soon compensated for the loss, but now there's no backup for the backup. For a $100 million spacecraft that provides a key link in NASA's space communications, that's an untenable situation.

"Normally you try to design for no single-point failure," says Hoffman. "Had we not had redundant Earth sensors on that TDRS, I would be in a panic someplace, trying to figure out how to point that thing tomorrow instead of next year. But now we have time to bail ourselves out and figure out what to do if we lose the backup sensor." The satellite has four dish antennas, and Hoffman hopes one of them can be tracked carefully from the ground station to provide the same information as the Earth sensor would.

To keep a satellite aligned, controllers use references like

RICHARD NOWITZ (c)

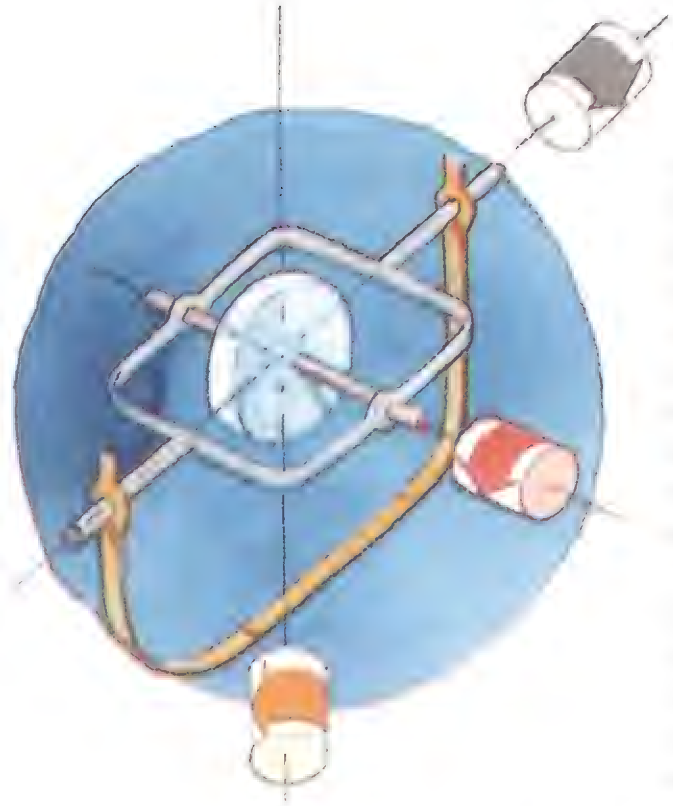
With a dozen satellites in orbit and plenty more on NASA's drawing board, Henry Hoffman's guidance and control branch has a lot of balls in the air.

the sun, Earth, and guide stars, which they plot on an imaginary spherical coordinate system with the spacecraft at its center. Called "the celestial sphere," the coordinate system has poles, an equator, meridians, and parallels but no corporal features like continents or oceans. It is used to calculate direction, not distance. All the points on the sphere are equidistant from the satellite at the center, even though the real distances are usually vastly different.

Astronomers have used such spheres for centuries to trace the movements of the planets, but attitude determination—that is, finding out how something in space is pointed—started only on October 4, 1957, when engineers began to track the Soviet's Sputnik. Satellite controllers picture their spacecraft at the center of this ancient spherical map, then describe its attitude using the nautical reference system with which every airplane pilot is familiar: three axes intersecting at right angles and indicating roll, pitch, and yaw.

"Engineers have to use their hands when they talk about satellite control," says Stephen Paddack, the director of the advanced missions analysis office at Goddard. As Paddack starts to talk about control axes, he points his right index finger directly away from him with his thumb straight up, like a child using his hand as a gun. His third finger points to his left, perpendicular to the other two, to become the third axis. Paddack rotates his hand while he speaks to point these axes at various imaginary targets around the room. "We use the forces of nature created by spinning an object to control spacecraft," Paddack explains. "Our work is based on the laws of Newtonian mechanics."

Satellite pioneers exploited one such law—that a spinning body resists change in orientation—to maintain the attitude of orbiting Sputniks, Vanguards, and Explorers. These early satellites were "spin-stabilized." Once an object is set spinning, whether a planet, a football, or a satellite, some force is required to change its rate of spin or the direction of its spin axis. The bigger the object and the faster it's spinning, the more force it takes. This is the physical law that makes gyroscopes, or gyros, standard equipment for determining a spacecraft's attitude (see diagram, above).



A gyroscope is a rapidly spinning wheel or rotor suspended in a gimballed framework. The rapid spin of the wheel holds it stable along its spin axis when the framework is rotated. (The rotor on a spacecraft's gyro typically spins at 48,000 rpm.) A rotation around the input axis causes the gimbal supporting the output axis to turn. This enables precise measurements of a rotation in one axis.

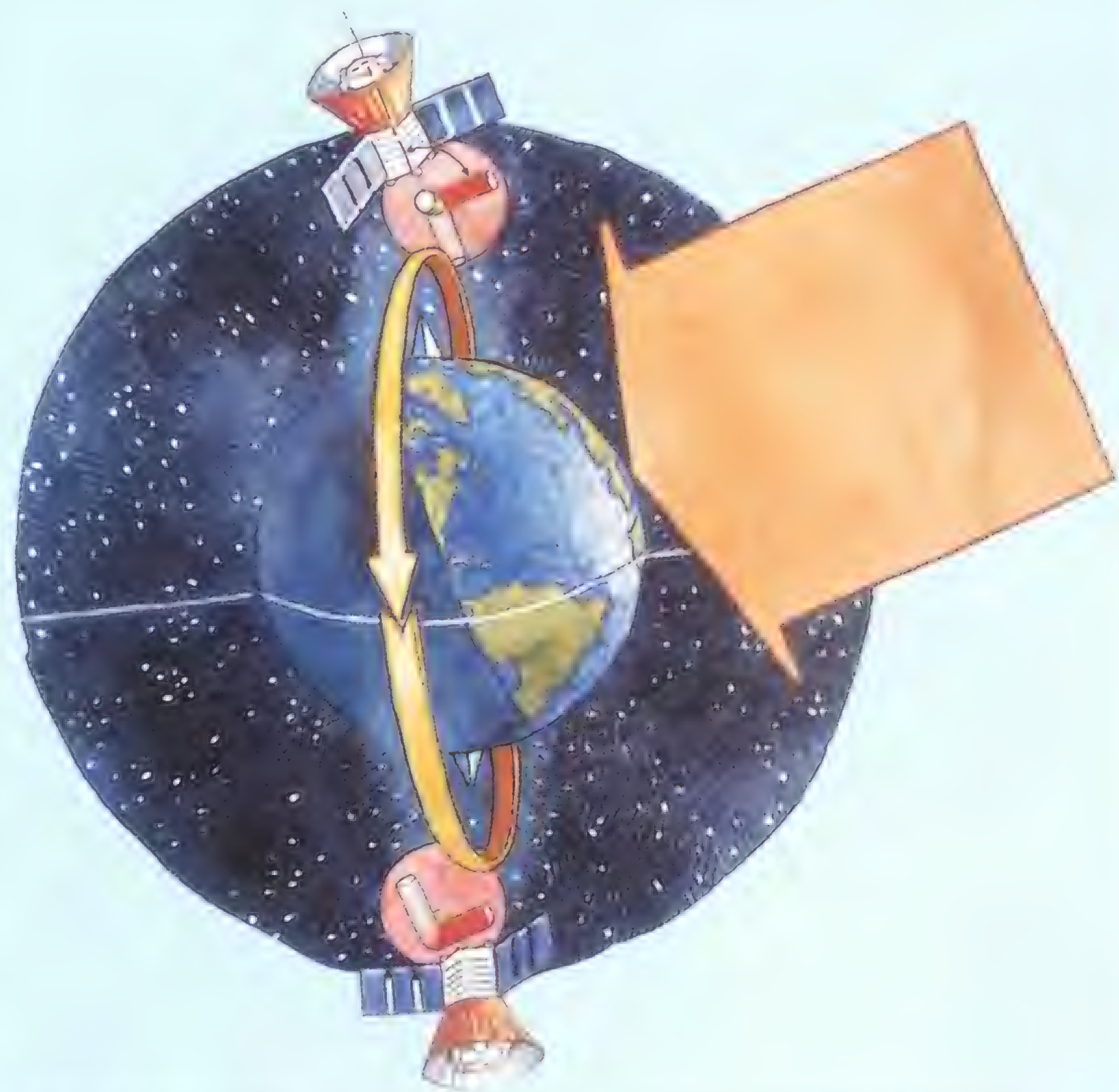
An Earth horizon sensor is a telescope with a narrow field of view that outlines a cone in the sky as the spacecraft spins. When the cone crosses from space to Earth, the change in infrared or visible radiation triggers an electronic pulse. The sensor generates a second pulse when it crosses from Earth back to space. By computing the time between the pulses and combining that with the size of Earth and the satellite's spin rate, the control system calculates its attitude toward Earth.

All precision-pointing spacecraft like the IUE rely on at least three gyros for fine attitude control. But gyros are notoriously unreliable. The IUE started out with six, but it lost one during launch and two more shortly thereafter, operating on three until 1985. And then there were two. That's when Hoffman substituted the IUE sun sensor, determining the spacecraft's movement around one axis by measuring its angle to the sun.

Then he decided that if another gyro broke, the sun sensor might be good for readings on a second axis as well. Last March, after his team had designed the software, technicians radioed a new set of control laws to the IUE.

Six technical analysts, twice the number usually on duty, sat in a cramped mission control room on test day waiting patiently for the IUE to come in sight of a tracking station in Madrid. That station, which normally handles IUE operations for one eight-hour shift a day, was on line during the test as a backup control center. On the bare, institutional green walls of the IUE control room—one of many such rooms where technicians converse with the Hubble Space Telescope, the newly launched Gamma Ray Observer (GRO), and the other ten NASA satellites currently orbiting Earth—a color photograph of the Madrid station hung next to a drawing made after the IUE's successful conversion to two-gyro operation. The drawing showed an eagle with a rabbit in its claws; the caption read, "Flying lame, but still bringing home the quarry."

When the test began, the control room loudspeakers emitted a series of metallic chirps as the new software was transmitted to the satellite. A television monitor mounted in one corner near the ceiling displayed the star field visible through the IUE's telescope. Most of the action took place on computer screens, which displayed telemetry readings from the spacecraft in an ever-changing jumble of numbers and acronyms. To a trained eye, the screens showed the vital signs of the satellite: its attitude, temperature, power level, and instrument activity. During the test the analysts focused most of their attention on the three columns of numbers indicating the IUE's movements around the roll, pitch, and yaw axes.



WEB BRYANT (3)

COBE's Fine Line

The Cosmic Background Explorer satellite orbits Earth 559 miles up in a near-polar orbit. As it orbits, COBE's pitch axis (red) is held parallel to the sun line, and its yaw axis (gray) is held at a 94-degree angle away from the sun in order to protect temperature-sensitive instruments

This diagram shows the position of the spacecraft at the summer solstice, when the angle between the sun line and the equator is at its greatest (23.5 degrees). During this period of the year, COBE's yaw axis will be offset from the orbit plane. As the equinox approaches, the angle decreases between the sun line and the equator and the yaw axis will shift to point closer to the orbit plane. COBE'S roll axis (green) continuously points parallel to the direction of the spacecraft's motion, its velocity vector.

Running the test turned out to be a lot like shooting a movie—brief spurts of action surrounded by long periods of waiting. The new software ran the IUE through 20 different control modes, using a single gyro in various combinations with the sun sensor and a star tracker, a fine pointing device that can lock onto a single star and measure the spacecraft's drift relative to it.

Each time the spacecraft was shifted into a new mode, readings in the attitude control columns would rise, signalling a sudden wobble on the spacecraft. Just as quickly, they would drop back to normal levels. The technicians call the wobbling motions "noise" and can tell from the signals exactly where and how the noise was created. "With that data we can go back and refine some of the algorithms in the software, clean them up so that the controls are a lot tighter," says IUE control center manager Mike Myslinski. "We expect to work out the vast majority of noise."

When control system engineers substitute a sun sensor for a gyro, as Myslinski did, or re-program a spacecraft to ignore a directional device, they say they are "fooling it" or "tricking it into believing" in a world that isn't real. The spacecraft are highly programmed robots, equipped by their creators with reference systems and control loops, a set of automatic reactions to a vast set of circumstances. The Cosmic Background Explorer, a recent NASA success that over the past two years has confirmed many of the predictions of the Big Bang theory, has a uniquely complex attitude control system, and it had to be fooled just four days into its orbit. "COBE has 23 boxes just for attitude control," says Femiano, who is the technical officer for COBE's gyros. His three fingers automatically assume the position as he explains why COBE rotates at approximately 0.8 rpm around its spin axis as it sweeps the sky in a near-polar orbit around Earth (see "COBE's Fine Line," above). COBE also had to be offset from the sun at a 94-degree angle to maintain the temperature of two instruments, which were cooled by liquid helium so they could make fine measurements of very faint radiation.

Four days after its 1989 launch, the satellite started a dangerous tilt toward the sun. "My gyroscopes," Femiano says. "We're not sure exactly what happened because we have limited telemetry. We don't know whether it was a mechanical problem or electronic. Probably electronic. Probably a short circuit." It sounds as if he's been over this ground many times. "But it could have been mechanical," he says mostly to himself.

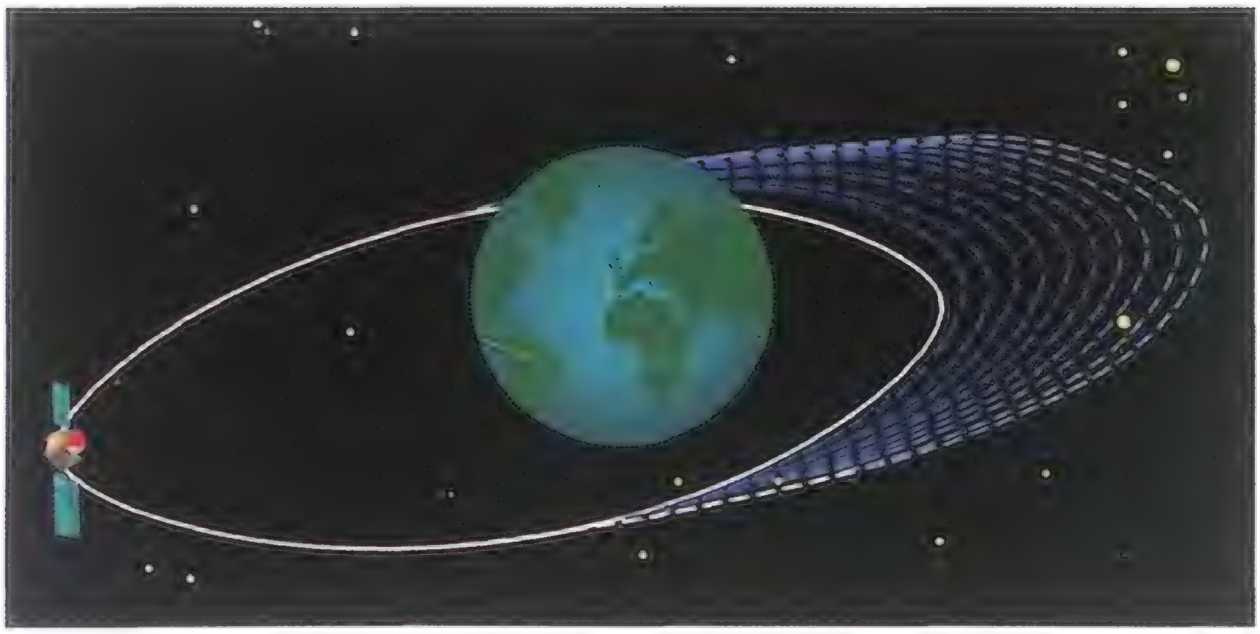
"Gyros are funny like that," Femiano continues. "The two on IUE that are still working always had good drift-rate characteristics. The others have always been much rattier."

The brief panic over COBE ended with a pretty easy fix. The spacecraft has six gyros; the controllers simply tricked it into ignoring the bad one. It isn't always that easy.

In September 1988 half a dozen engineers at GTE Spacenet were in the company's control center in Princeton, New Jersey, watching computer screens fill with data from GStar 3. The communications satellite had reached its elliptical transfer orbit and was ready for a final boost to geosynchronous orbit, a parking space about 22,300 miles up where satellites match the speed of the Earth's rotation so that they remain over the same point on the ground.

GStar 3's apogee kick motor fired to take it to the higher orbit. Thirty-seven seconds later, the engineers knew they had a problem.

"It was like one of those firecrackers that spins around until it runs out of fuel," recalls Bob Bennett, GTE's director of satellite operations. GStar 3



GTE SPACENET CORPORATION

Engineers at GTE kept nudging GStar 3 until it changed its ways and left a useless elliptical orbit for a productive life at geosynchronous.

spun furiously for 18 seconds. When it stabilized, it was 12,000 miles away from its target orbit. The engineers frantically tracked the satellite for 36 hours to fix its orbit. They spent the next six weeks analyzing the misfire and decided to try again to get their satellite to its destination.

Like most satellites, GStar 3 was equipped with thrusters and fuel for "station-keeping"—small, periodic adjustments that keep the satellite aligned properly. The thrusters counteract such subtle forces as radiation pressure, interference from Earth's magnetic field, or a gravity differential between the lower and upper end of the satellite. With nozzles the size of tea cups and a maximum thrust of 0.1 pound, the thrusters are not intended to push a heavy satellite 12,000 miles. But it was either that or lose the satellite.

GStar 3 had to be turned on its side for the improvised maneuver. "We had to fool the spacecraft into thinking it was upright by injecting new parameters into the attitude control electronics on board," says Troy Ellington, GTE vice president of engineering and operations. The engineers also faced strict fuel limitations. "There was a good chance that we could get to where we wanted to go but have no fuel left for station-keeping once we got there," Ellington says. "We calculated that we needed on the order of at least 99.8 percent correct burns; one bad burn could've ended the whole process."

During every orbit, the control team waited for the moment when the satellite approached its farthest point from Earth. Firing the thrusters at that point would have the most effect on the orbit, the same technique you apply intuitively when giving a child a push on a swing. It took a team of 70 engineers and technicians nearly 13 months to make the 166 precisely controlled burns that finally brought the satellite into geosynchronous orbit with enough fuel left for five years of station-keeping. The satellite started operations in September 1989. "We had one hell of a party," says Bennett.

During a 1984 shuttle mission, astronaut Dale Gardner nabbed the Westar VI satellite and brought it home for repair.

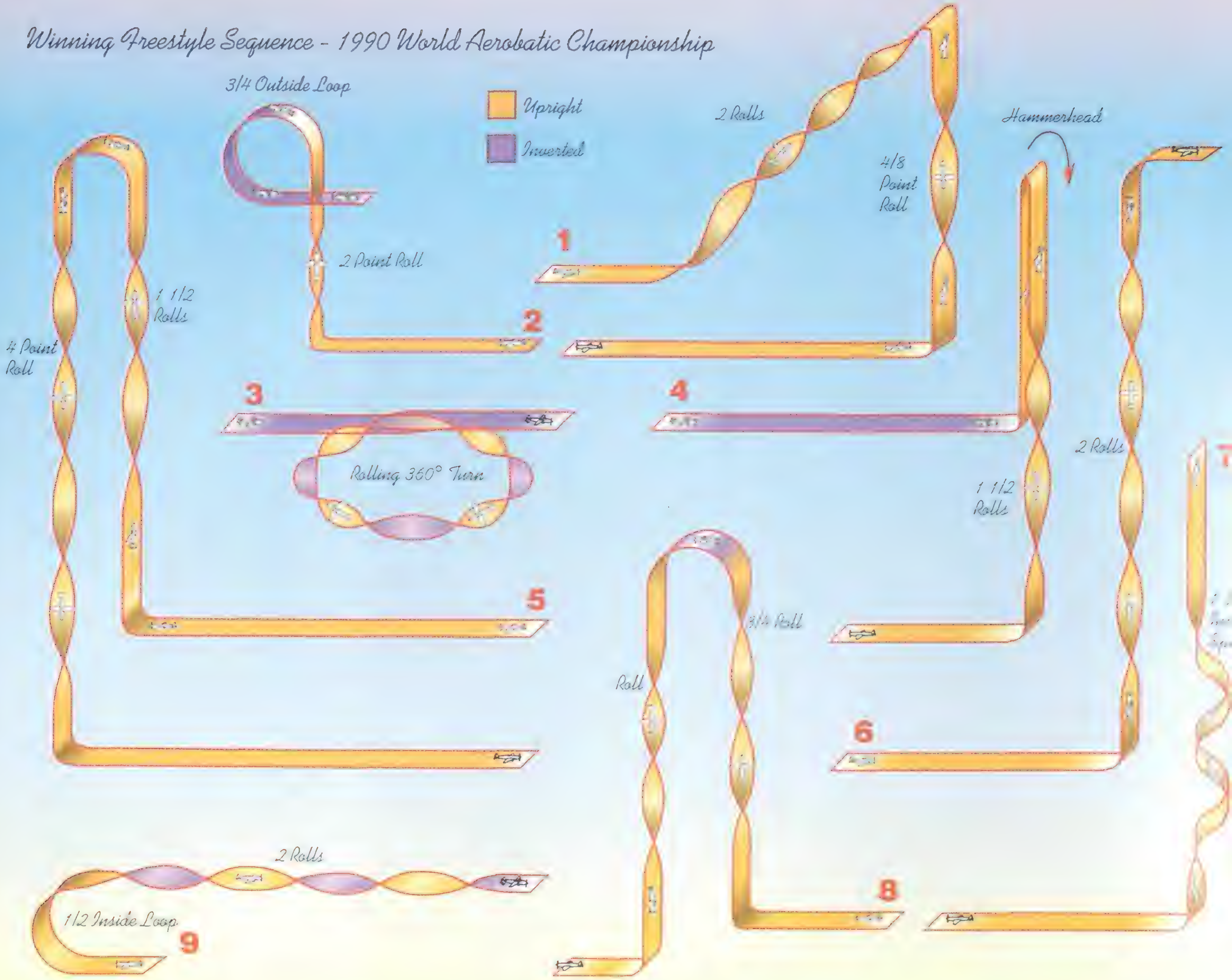
NASA

Despite the ingenuity of the engineers in the guidance and control field, sometimes the only way to rescue a satellite is to go up and get it. At the end of 1980, the Solar Maximum satellite, a Goddard creation built to study solar flares, lost three fuses vital to its guidance system and so became eligible for the first in-orbit repair job. In April 1984 Commander Robert Crippen guided the *Challenger* to a rendezvous with the satellite, and the crew brought it into the shuttle cargo bay, replaced the faulty parts, and sent it back to observe the sun for another six years.

In the three years between the fuse failure and the salvage mission, Hoffman's branch at Goddard managed to keep the satellite in a "safe hold" or "rotisserie" mode—a slow spin that keeps one of the pair of solar panels always pointed toward the sun and enables solar heat to be evenly distributed around the satellite's surface. Having lost three of the guidance system's reaction wheels—the equipment that would usually have controlled Solar Max's spin—Hoffman and engineer Tom Flatley used the spacecraft's magnetic torquer bars, instruments that align the craft by interacting with Earth's magnetic field, to start the satellite rotating.

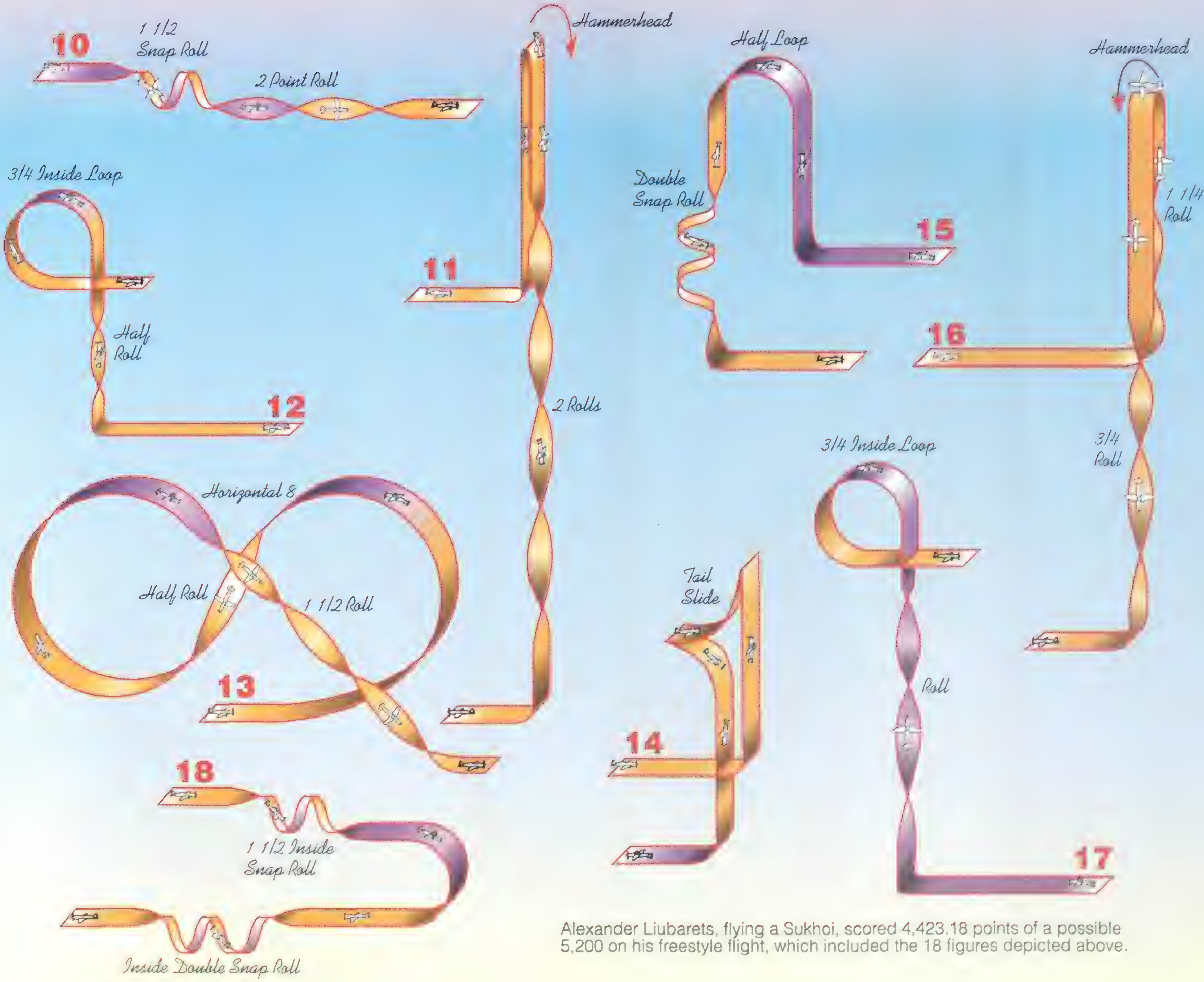
Seven months after the Solar Max repair, NASA sent *Discovery* to retrieve two commercial communications satellites, Westar VI and Palapa B2. This time the astronauts brought the satellites back to Earth to be refurbished and relaunched.

Early next year NASA will perform another rescue with the shuttle. Intelsat will pay the agency $90 million to repair its latest satellite, Intelsat 6, a $150 million comsat waiting in a useless low orbit for the first flight of the shuttle *Endeavour.* But well before the world is treated to the dramatic scene of an astronaut wresting a satellite into the shuttle cargo bay, engineers will spend months in an obscure control room, coaxing the satellite into a slow, stable spin and helping it get its attitude adjusted.



Ballet Among the Clouds

The contest for the Nesterov Cup is not only the world's premier aerobatics competition – it's also one of the best kept secrets in sports.



Alexander Liubarets, flying a Sukhoi, scored 4,423.18 points of a possible 5,200 on his freestyle flight, which included the 18 figures depicted above.

by Larry Lowe

Illustrations by Dale Glasgow

As his monoplane falls out of the sky like some monstrous blue maple seed, Peter Anderson sees a row of trees swirl past his windshield. He lays the stick forward and the resulting jolt slams him against a rigid web of seat belts and harnesses. Precisely one and a half revolutions later, the snap roll stops. Anderson executes a 45-degree dive, the airplane upside down. Directly off the left wing, the judges hang from a grassy ceiling. Anderson steals a glance at the small card in the middle of the instrument panel.

As the airspeed indicator winds past 200 mph, Anderson pushes hard on the stick and is brutally flung around the outside of a diving arc. The airplane claws through part of an outside loop until it points straight up into the cloudless sky. Airspeed decreases rapidly. Split-second timing is necessary to retain enough speed for a clean vertical snap. *Now!*

Six hundred feet below lies a neat grass airfield displaying a row of 19 flags. Each represents one of the nations participating in the 1990 World Aerobatic Championships, held last summer at an 800-year-old Swiss village named Yverdon-les-Bains. Seventy-nine pilots have come to Yverdon to compete for the Nesterov Cup, the crowning honor of aerobatic flying. In the row nearest the runway, the French team's elegant, sinewy CAP 231s hold the pole position. Behind them wait the Soviets' mighty Sukhoi Su-26s, a glowering quar-

tet on aeronautical steroids. In the back row sits a menagerie belonging to the U.S. team: three Pitts Specials, two single-place Extra 230s, a two-place Extra 300, a CAP 231, and a Laser, as well as the unique biplane *Snargasher* and the very unique monoplane *Ratsrepus.*

Anderson, a 38-year-old from Fowler, California, is participating in his first world championship. He's an alternate member of the U.S. team, but he's flying as if Chuck Yeager, Mario Andretti, and Olga Korbut have squeezed into the cockpit beside him. The urge to cheer grows as each new pattern evolves, but except for a few other pilots, there is nobody to applaud. All day long Anderson and a host of others have been performing feats at the pinnacle of piloting, *and no one is watching.*

Who are these guys?

It's a mistake to equate them with airshow performers and a few lazy summer afternoon loops and rolls. The pilots who fly competition aerobatics form a dogged group that steadily expands the limits of man's ability to design, build, and fly fixed-wing aircraft. The arcane culture that has developed around the sport consists mainly of its own pilots. At the exact center are a few good enough to compete effectively at the world championship, maybe two dozen or so of the pilots who have come to Yverdon.

What makes the sport substantially more difficult than merely flying precision figures is the invisible cube of sky that is known simply as "the box," in which the competition pilot must confine all of his activities. Flying at a high speed of 300 mph, it takes a pilot approximately 10 seconds to cross the 1,000-meter box in any direction. On the ground white lines mark the edges of the box, and a white cross its exact center. The bottom of the box is 100 meters—330 feet—from the ground.

Aerobatic pilots form an international group, and for years this competition, held every two years, has served to facilitate cultural exchange. European pilots especially have developed a wide interest and expertise in this most intricate game. At the moment, a design war is being waged by France's Avions Mudry, the Soviet Sukhoi Design Bureau, and Germany's Walter Extra. (Why no one has sent Burt Rutan a set of rules, a check, and a mandate to return the United States to aerobatic design supremacy remains a mystery.)

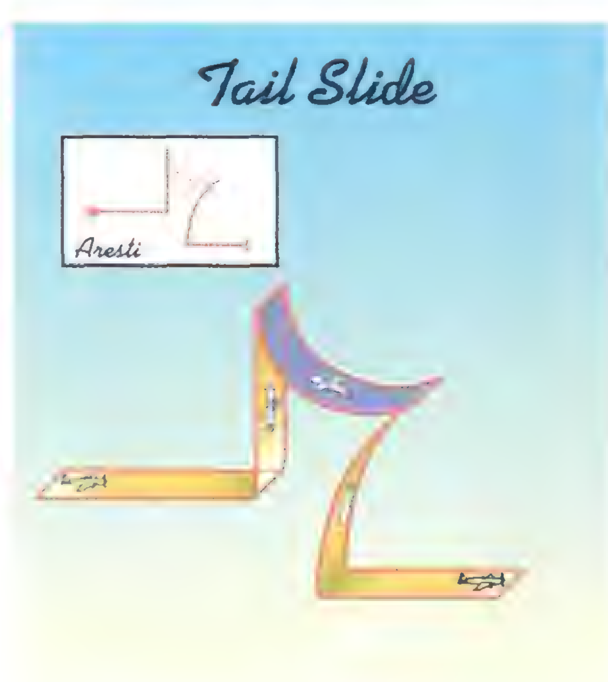
The competition is reminiscent of the Olympics, complete with the traditional rivalry between the United States and the Soviet Union. As usual it's a David and Goliath confrontation. The Soviet government maintains a program in aerobatics, but the U.S. team depends on Sporty's Pilot Shop in Batavia, Ohio, and a handful of other sponsors to help pay the bills. To get to Yverdon, the U.S. pilots have had to reach into their own pockets.

Regardless of nationality, competition aerobatic pilots have a common language in Aresti, an international system of visual notation that provides the framework for competition. Named after its creator, Spain's José de Luis Aresti, this system imposes an invisible lattice of lines and angles against the fluid nature of the air. The Aresti symbol for a one-and-a-half-turn inverted spin with an upright entry is as recognizable to a Hungarian pilot as it is to his Dutch counterpart.

Each pilot assembles a flight sequence from the set of figure elements in the Aresti manual. Three sequences—Known, Freestyle, and Unknown—make up the contest for the Nesterov Cup. The trophy awaits the team whose pilots tumble with the highest degree of precision across a small piece of the sky.

In a converted hangar that serves as a briefing room, the competitors at the 1990 world championships gather each morning to listen to the familiar rules of flight. After the briefing the judges repair to a remote location on the far side of the valley, and the contest director calls each pilot to pick a Swiss chocolate coin from an array on the briefing table. Each pilot turns his coin over to reveal the number on the flip side. There is a hush during the ritual. Right now, at least, no one wants to be number one.

The order in which the pilots fly is the single biggest random element that influences who will be world champion. Pilots suspect that most judges "save" a little when they score early flights in case a later one is better. The story of Claude "CoCo" Bessière, a universally liked Frenchman, is now legend. In 1986, CoCo, having drawn the



The Nesterov Cup awaits the team whose pilots tumble with the highest degree of precision across a small piece of sky.

odious number one, turned in a stunning, flawless sequence. The scores, however, placed him 18th. He was, the pilots tell you plainly, robbed.

Once the order of flight has been determined, the teams huddle to review it, then disperse to wait patiently for their turn in the box. Depending on the draw, a pilot can go the better part of a week without flying. Boredom, which can dull the fine edge of competitive skill, is as dangerous to the pilots as gusty crosswinds.

The first flight at every contest is the Known sequence. It serves to weed out the true contenders from those who show up with little more than an airplane, the proper paperwork, and the entry fee. The Known offers no room for in-flight innovation: the aerobatic pilot may not elect to do a double roll instead of a triple in mid-performance, as the competitive ice skater might. Instead of a reactive competition, the Known offers pilots a set of restraints and complexities, making it a test of predictive engineering.

The only figure in a sequence that a pilot has absolute control over is the first, when he or she can circle the box like a shark, waiting for altitude to provide a comfortable margin of energy, waiting for position to permit the best placement of the entry dive, waiting for the mind to come to the moment of commitment—and decide to attack. At some point in space, energy, and time, mental tumblers fall into the proper positions and the pilot noses the airplane over, increasing airspeed and, not incidentally, noise.

A long howl as the pilot dives for airspeed to deliver the first figure announces the start of each sequence. As far as the pilots are concerned, the louder the better. The flight proper is a rhythmic alternation between a roaring episode at the bottom of the box and a quiet one at the top. The airplane drives up and down, working its way through the sequence.

Once the pilot enters the box, judging begins. The judges sit to one side of the box, sufficiently distant from the edge to observe the action clearly. The aircraft parade past them as the contest day settles into a pace of three or four flights an hour. Each judge has two assistants. The caller maintains a steady but discretely spaced stream of verbal shorthand to prepare the judge for each element of each figure. This leaves the judge free to keep his eyes on the aircraft while delivering an equally steady stream of scores and comments to the writer, whose sole task is to capture them.

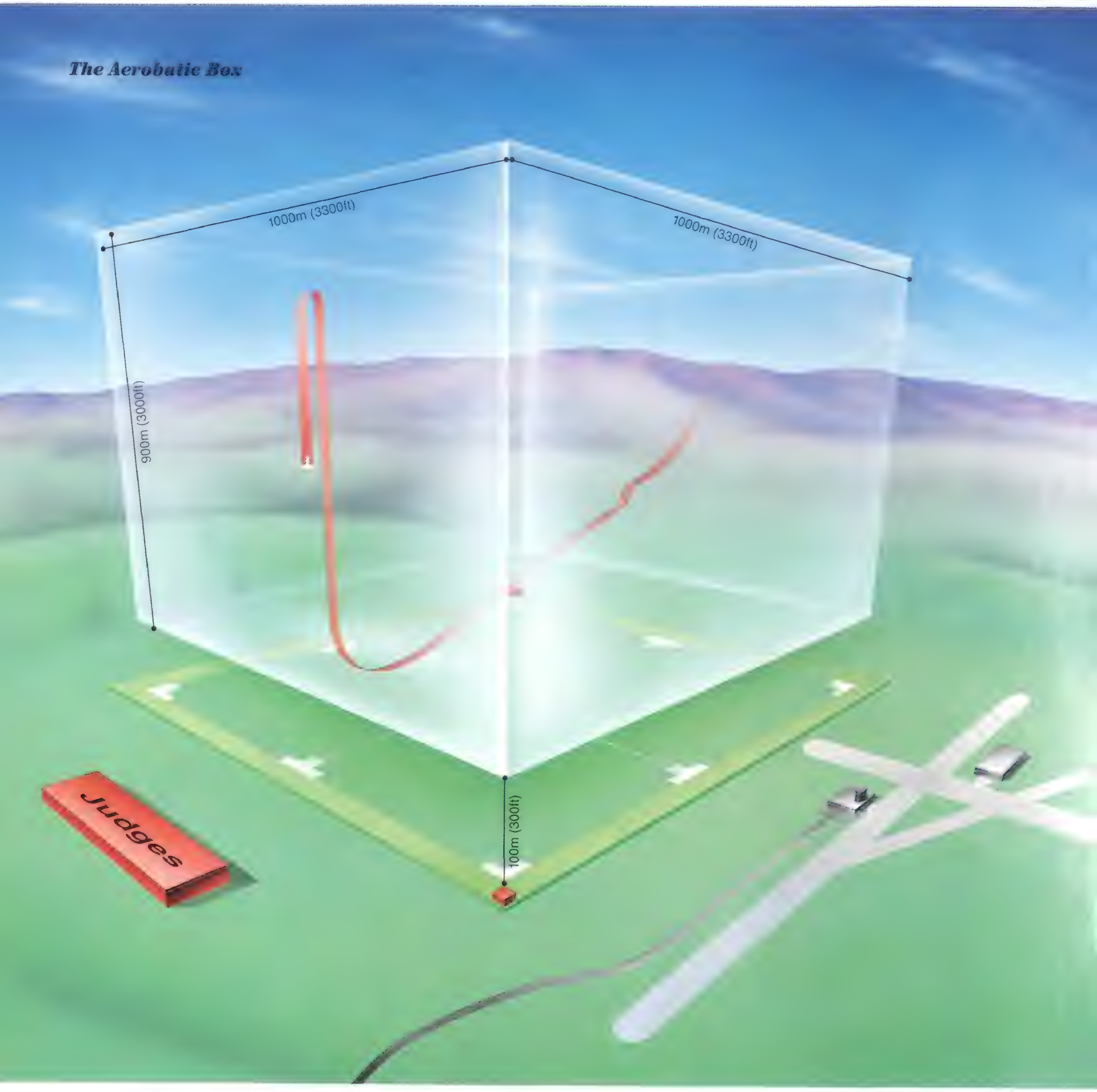
Ten teams of judges collaborate to produce the raw data for the scoring computers. During a sequence all three members of a judging team track the progress of the pilot intently. Their heads mirror the position of the airplane, bobbing up and down and back and forth in stately pursuit, like three radar dishes tracking the same target.

The judges sit in easy chairs but their task is as demanding as that of the contestants. During a typical day, a judge will score over a thousand complex figures, each with as many as eight individual components. The mind-numbing mental marathon of judging stretches over two weeks. Finding judges with the experience, a critical eye, and the patience to sit in a cornfield for days on end is difficult.

The judges' heads bob up and down and back and forth in stately pursuit of the airplane, like three radar dishes tracking the same target.

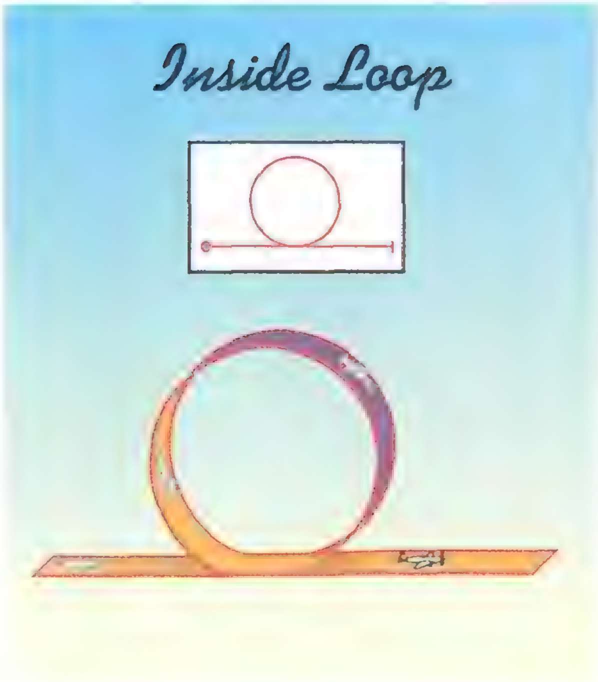
The subjective nature of judging sometimes provokes complaints. Each country supplies one judge, and this inevitably contributes to national prejudice in the scoring. After the early competition the U.S. pilots grumble that the low-horsepower airplanes are getting the low scores. From a pilot's point of view, perfection of flight, not performance of aircraft, is the issue. "A lower-horsepower airplane will cover less sky getting a specific figure done," explains chief judge Mike Riley, whose regular office is the left seat of a British Airways Concorde. "What this really amounts to is less time for the judge to scrutinize the figure." The judges don't harbor any sinister prejudice against low-powered equipment, Riley asserts. "It's simply that a higher-powered aircraft will give them more time to appreciate the details of a figure and score it well, if it deserves it."

Watching a tiny Pitts Special roar through the sequences like a hummingbird on amphetamines bears this out. Once the very symbol of U.S. aerobatic supremacy, these stubby overpowered biplanes are now obsolescent in the face of the latest generation of airplanes, epitomized by the Sukhoi. A big radial engine and enormous geared paddle-blade propeller



An invisible but closely watched cube of airspace known as "the box" defines the arena of competition for aerobatic pilots.

enable the powerful Soviet monoplane to command the entire vertical range of the box. The bigger the engine, the longer and straighter the lines. Both camps have a point. Yet it frustrates the Americans to know they're flying well and not scoring any higher.



When the Known ends, CoCo Bessière holds a paper-thin lead of three points over the nearest pilot, Jurgis Kairis of the Soviet Union. The first-round scores place the Americans at the far edge of contention for the team trophy. The leading male pilot for the United States, Clint McHenry, is a little less than 200 points out of first. Another American, Lee Manelski, isn't far behind. (Six months later Manelski will be killed in an air collision near Los Angeles.) Patty Wagstaff, also from the United States, has a chance at the women's title. This is her third championship and she trails Natalya Sergeeva of the Soviet Union by 80 points, a margin she might overcome.

Back at the hotel that night, cricket and soccer scores from Britain dominate the sports news on television.

The second part of the contest is the Freestyle sequence. The rules call for a mix of figure types, a maximum number of figures, and a total difficulty factor. Freestyle, more than any other sequence, provides a pilot with the opportunity to display the lines, angles, arcs, fractions of turns, rolls, and spins that make up his or her aerial vocabulary. Figures are created from these elements like lines of verse, with a sense of timing and rhythm. A sequence is a graphic sonnet in the sky, a poem with six dimensions of freedom.

In a Freestyle, the first figure usually expends all the energy the airplane can muster in a vertical line drawn directly in front of the judges. This proves at the onset that the pilot has full command of the vertical axis. If the first figure goes well, the pilot pauses to "draw a line"—a moment of level flight defining the separation of two figures. If the second figure is cleanly done, the airplane is in position to enter the third, and so on through the sequence.

Every pilot hopes each flight will allow him to "get one going"—ride the rhythm of the flight with mental as well as physical agility. If a flight does get going, an aerodynamic cadence of correctness takes over. Like a jazz musician searching for that indefinable essence of delivery, the aerobatic pilot searches for the point at which time suspends and the *now* of the flight flows across the sky. A good flight has an intangible feel that leaves a pilot with a tremendous feeling of oneness with the airplane. When that happens, "everything is in order," says Linda Meyers, a veteran of five world championships and the managing director of an air museum in Florida. "The entire world is under total control."

A well-designed sequence has an artful logic, a theme ebbing and flowing through it. The better pilots construct a Freestyle sequence intended not only to meet the rules but to reflect their contest philosophy and showcase their airplanes as well. Freestyle also offers the best glimpse of the difference between the moderate, exacting American philosophy and the aggressive European style.

The so-called California Freestyle, pioneered by Lee Manelski and others in the Los Angeles area, is the basis of the U.S. strategy. One of their innovations was to abandon the traditional figure flown in the center of the box, which reduces pilot workload.

Another American tactic is selecting figures of average difficulty. This is a defensive strategy. The Soviets, French, and others favor a more flamboyant approach that showcases the characteristics of their aircraft. Their sequences begin and end with innovative, difficult figure combinations designed to impress judges with sheer bravado.

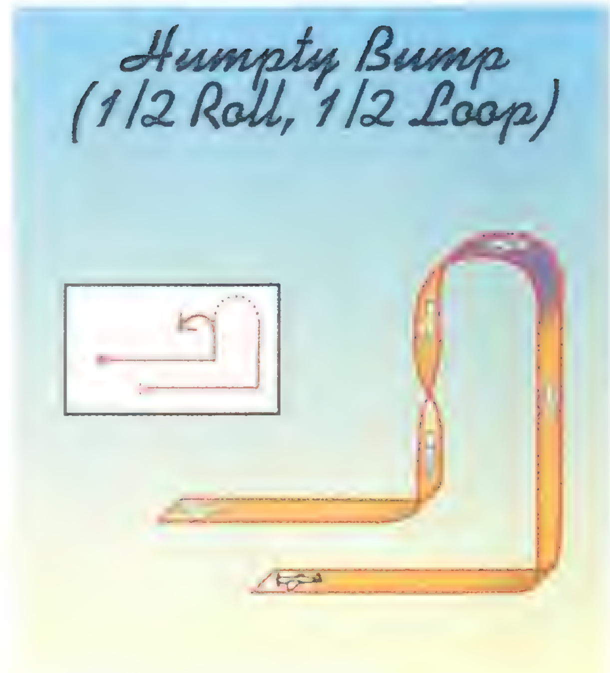
The Americans' strategy, it can be argued, tends to work against them. On paper, they stand a better chance of consistently scoring higher by perfecting a median class of figures and presenting them like clockwork to the judges. In practice, they suffer in comparison to a pilot who commences with a figure that was unflyable before the development of a 360-horsepower aerobatic wonder weapon.

At the completion of the Freestyle flights, CoCo has increased his lead and is pulling away from the pack. He's a hundred points ahead of his countryman Patrick Paris, who has passed Nicolai Nikitiuk of the Soviet Union. The French are showing signs of running away with the contest, but they don't want to jinx

Like a jazz musician searching for that indefinable essence of delivery, the aerobatic pilot searches for the point at which time suspends and the now of the flight flows across the sky.

Pilots worry about "brainlock"—that sickening sensation when you pull out of a vertical dive at near 200 mph and have no idea what figure comes next.

the works by talking about it. It's too fragile a competition for prediction. Clint McHenry has gained a couple of positions, from ninth to sixth, but remains well out of contention. Peter Anderson and Henry Haigh have joined him, but a tight cluster of Soviets is ahead of the Americans. Patty Wagstaff still has a chance. She has halved the gap between herself and Sergeeva, and they have both risen in the standings.



Back at the hotel, the television sports coverage is alternating between a swim meet in Germany and the Finnish Grand Prix.

The final arbiter of aerobatic skill is the Unknown sequence, which is presented to the pilots no more than 24 hours before they fly it. For pilots whose flying is based on planning and preparation, it represents a difficult challenge. The competitor can't fly the sequence before being scored and hence must assemble the figures barehanded.

"There are 10 or 12 or 14 guys here that could win it," says Haigh. "Any one of them could win it if the cards happen to fall their way." Haigh should know. He made one of the finest aerobatic flights ever witnessed during his Unknown two years ago in Red Deer, Alberta, and he appreciates the unpredictability of the circumstances required to win. "I'm very proud to have won the world championship, but I'm also very humble that things fell into place for me."

The Unknown is the flight that makes pilots stay awake nights worrying about "brainlock"—that sickening sensation you get when you pull out of a vertical dive near 200 mph, check wings level, head right toward the edge of the box—and realize you've no idea what comes next. Unless you can instantly reorient yourself with the flow of the sequence, you are doomed. There's no choice but to wag the wings, circle once, and start over where you left off, a choice only slightly less costly than taking a zero for a figure.

At Yverdon, the Unknown becomes the subject of some controversy when the U.S. team decides to protest the sequence. The team's consensus is that, particularly for the lower-powered airplanes, it's potentially dangerous. The next day the international jury, seven individuals who administer the contest, produces a revised version. To demonstrate that the new sequence is flyable, a jury member takes off in an older Zlin. He starts at the very top of the box, much higher than an aggressive contender would, but he ends well above the bottom. The point is made.

Now, in the waning days of the contest, American hopes start to falter. Patty Wagstaff, having drawn a high number, misses the calm first day of Unknown flying, then draws the second flight on the next day. She must fly in a wind that's near competition limits.

The pilots are always concerned that prevailing winds will blow the airplane to one side of the box. While the air the pilot is working in drifts southwest at 15 mph, the markings on the ground stay fixed. Every figure must be hedged slightly, skewed to compensate for the drift. In a strong wind, the pilot who does not pay fastidious attention to extending his lines upwind and shortening those downwind will eventually face the pauper's choice of either distorting a figure to keep it inside the box or taking the airplane outside the box to execute the figure correctly.

For the first two-thirds of her flight, Wagstaff's figures are well formed. Headed downwind, she faces an out if she doesn't hurry a turnaround figure. There's only a moment to choose a tactic. Flying inverted, she pulls the nose down, does a roll, and rushes the half-loop that turns the airplane around. This results in less speed than she needs on the upline. The figure thus far is acceptable, if stunted. The snap roll begins at too slow an airspeed, doesn't respond as quickly as it should, and wallows past the point she wants as it comes to a halt. In less than a second, the failure of her Extra to come out of the roll dashes her hopes of beating Natalya Sergeeva. It will be two years, perhaps six, before she can get this close to her dream again.

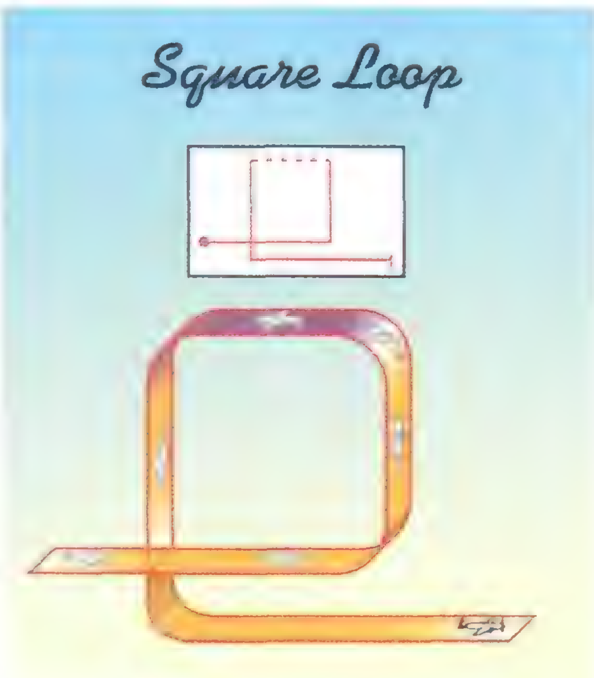
Down on the ground the team lets out a collective breath as Wagstaff maintains her composure and continues the sequence. The mental focus during a flight has to be on the present and the very-soon-to-be. If a pilot doesn't dismiss an error, he or she risks losing the fine edge of concentration amid the swirl of events

and forces in the cockpit.

When a figure starts to unravel, the problem behaves like a chain reaction. If the pilot finishes one figure in a position too aerodynamically awkward to begin the next, the form of the second suffers. It's a grimly fascinating spectacle to watch a pilot caught low early in a sequence struggling gamely through the remainder of the flight, cheating every figure to minimize altitude loss, cruising across the bottom of the box and trying to store every erg possible before pulling up into each vertical turnaround done on the hairy edge of loss of control.

Sly deception occasionally enables an experienced pilot to get away with an error. From some angles a roll that over-rotates is hard to detect. The giveaway is the movement of the wings as the pilot jogs them to the correct attitude. Skilled competitors will hold the over-rotation and fly away slightly askew, smoothing the error away during the transition to the next figure in the sequence. If a judge doesn't see a correction he may not notice the error, or at least not grade it down quite as harshly.

Out on the flightline, veteran Alan Bush is coaching Peter Anderson. Bush, a USAir captain from Florida, has a priceless asset as coach: he's flown the Unknown. He knows its pitfalls and opportunities, and he takes Anderson step by step through the sequence. In place of airplanes, the two use their hands. Anderson flies his fingers in formation with Bush, who punctuates a barrage of verbal detail with abrupt changes in hand attitude. The pair dance a duet on the grass.



In what is so clearly an individual sport, this is a unique demonstration of teamwork. It wasn't so long ago that the U.S. team operated more like a group of individuals in competition with one another. In the past, some members returning from a flight didn't even bother to tell their teammates the wind direction. Now Bush is giving Anderson the equivalent of a practice flight in the hope that Anderson will use it to beat him. Anderson intends to use it as much to sneak the Americans past the Soviets into second place as to improve his own standing.

Finally, time. A contest helper tells Anderson to get mounted up. Comes the ritual of putting on the airplane. Checking the parachute straps. Checking the five-point harness that will hold him in the airplane. Checking the sequence card at the center of the instrument panel.

Time for engine start. The propeller turns once, twice, then catches. The canopy closes. As the airplane taxies out, several well-wishers flash thumbs-up or wave. With the power on, Anderson loses any vestige of individuality: in the sky, pilot and airplane become one, climbing out in an orderly fashion into the gusty late morning sun.

The flight goes like clockwork. Using the sky as a sheet of drafting vellum and the airplane as an engineering pencil, Anderson etches the figures one by one. He combines execution of each figure with planning for the next. A rhythm develops. He's got one going. Like the pieces of a jigsaw puzzle assembling themselves as they pour from the box, the figures of the flight fall right into place. On the ground, team members stop to watch. Trainer Ron Cadby's fingers trace a sequence card as the flight unfolds. Anderson works his way through his Aresti card, coming closer to earth. Finally, he pulls the nose up to climb at a 45-degree angle, pauses, nails a tricky one-half outside snap roll, pauses, and pulls the nose down to level inverted flight. He wags his wings and flies out of the box upside down. You can feel the wave of relief run through the group on the ground.

Late on a Thursday night, the U.S. team gathers on the verandah of the Hotel des Mosaiques in nearby Orbe. The contest is over, and they're awaiting official results from the airfield. A team member arrives with a score sheet, and the small group falls quiet. CoCo wins the contest going away, 200 points ahead of the closest competitor. His teammate Patrick Paris is second, followed by three Soviets. Peter Anderson, the highest scoring American, draws a cheer from his teammates for his sixth place finish.

This is a moment of triumph for the French, who have pursued the Nesterov Cup for years. The Soviet men take second, the American men third. Natalya Sergeeva of the Soviet Union

It's grimly fascinating to watch a pilot caught low early in a sequence struggle on the hairy edge of loss of control.

wins the women's individual championship, and her teammates win, yet again, the women's team title. Linda Meyers of the United States takes second place. The team results frustrate the Americans. The trophies won't be coming back to the National Air and Space Museum for display.

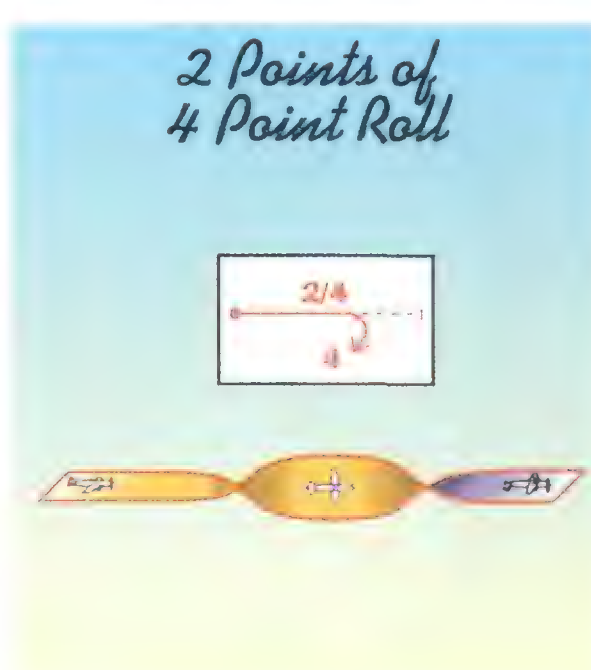
As the fat full moon rises over a small mountain range in the east, the U.S. team reflects upon what-ifs and if-onlys. Plans are discussed for the next contest, two years from now in Le Havre. The television over the bar gives a detailed accounting of a bicycle race in the Alps. Thousands of miles to the southeast, tanks are rolling across the Iraq-Kuwait border in the desert night.

The next day, all five members of the French team squeeze onto the top step of the stand to receive the award. In a moment of good humor during the ceremony, the second place Soviet team jostles the Frenchmen, sending a message to the proud pilots who toppled the U.S. aerobats from prominence two years ago. Welcome to first place, friends. Nobody stays there long.

Only a tiny audience—less than 200 people—watches the ceremony, which seems incongruous for a sport as rich and spectacular as this. World competition aerobatics, properly understood and presented, is a highly skilled, intelligent action sport with plenty of color and drama. Natalya Sergeeva is easily as amazing to watch in action as Martina Navratilova. With readily available competition aircraft and support technology such as scoring computers, the sport is ripe for expansion.

Perhaps someday there will be a television contract from ABC Sports or ESPN, although the few attempts to televise the sport thus far have failed to convey its essence. The television camera tends to focus tightly on the aircraft, but the subject of the judging is the form of the figure, something best seen from a distance. Figure skating offers us Dick Button to gush about "a marvelous triple axel," but aerobatics has yet to find a commentator with the skill and enthusiasm to interpret the action for a general audience. Maybe it's for the best. Right now one of aerobatics' most charming attributes is the innocence and nobility that go along with its amateur status.

Aerobatics has yet to find a commentator with the skill and enthusiasm to interpret the action for a television audience.



The next morning the U.S. team prepares to leave. One by one the big engines burst to life, the propeller blast shaking the dew off the grass of the Yverdon airfield. Maps replace sequence cards on the instrument panels. McHenry's Extra 300 trundles gently onto the end of the grass strip. The power comes in smoothly, and the big monoplane gathers itself into flight. The other airplanes follow in short intervals. McHenry makes a long, sedate, straight-out departure, then executes a gentle wide turn that lets the following airplanes cut across to join him. Haigh is the last to take off. This will be his final visit to the competition; in a salute to the sport that he was so much a part of for so long he peels away from the formation. In his airplane *Ratsrepus,* Haigh makes one final pass right down the flightline and arcs gracefully upward to catch his teammates, and the U.S. Aerobatic Team leaves Yverdon behind.

It's hard to predict the future of the World Aerobatic Championships. Sitting by his Zlin, Dutch pilot Frank Versteegh ponders the sheer size of the contest. "I really wonder how long we are going to fly this kind of competition," he says. "I don't think we will fly, in 10 years, a competition like this with 80 pilots and the judges in the field for 10 days." There is talk of corporate team sponsors and a grand prix formula for deciding the world championship. The world and aerobatics are both constantly evolving. In an era of severe economic hardship, how much longer will the Soviet Union be able to afford an aerobatic team? Will Jurgis Kairis be representing the Republic of Lithuania at the next contest? Could the French, with their marvelous CAP 231 and home field advantage, defend their title against a U.S. team flying a new 350-horsepower Rutan Sky-Dancer? Will the Japanese, who dominate radio-control model aircraft sports, someday discover full-scale aerobatics?

I cannot say. All I can do is glance furtively over my shoulder, pull you aside, and, in hushed voice, pass on a well-kept aviation secret. In July of 1992, at an airfield outside Le Havre, France, there will be two weeks of the absolutely finest exhibition of pure aeronautical skill the world has ever seen. You are the only one who knows this. Honest.

The Decades Past, the Decade Ahead

Martin Harwit
Director, National Air and Space Museum

Can the United States afford to compete in every research area?

After 30 years of spectacular discovery, it may take a great deal of careful thought to save American astrophysics from falling victim to its own successes. In the 1960s and '70s U.S. astronomers took the lead in every field of their discipline, inventing ingenious new telescopes that yielded deeper insight into the origin and evolution of our universe. These advances attracted the best young minds and called for more powerful telescopes and instruments. Along the way, expenditures rose to a point where thoughtful astronomers began to question whether the country could afford to lead on all fronts and whether the nation could long continue to support the many highly qualified aspirants pressing to join the field.

I remember meeting Ted Byram, a rocket pioneer from the Naval Research Laboratory, at breakfast during an Astronomical Society meeting in 1966. I hadn't seen Ted for some time and idly asked, "What's new?" He responded with a stunning account of an NRL X-ray telescope with which he, Herbert Friedman, and Talbot Chubb had just discovered two galaxies radiating virtually all of their energy in the form of X-rays. These galaxies contain hundreds of billions of stars, but previous measurements of their visible light had given little indication of the true outpouring of power. My first impulse was to figure out how three eminent astrophysicists could have made such an unlikely mistake in their observations. At the time, the existence of even one X-ray galaxy seemed not only incredible but physically impossible. Today, we know of thousands of them.

The 1960s led to other spectacular discoveries, so strange and exotic one had to invent names for them: quasars, pulsars, masers, X-ray binaries, infrared stars, and the microwave background. And the 1970s and early 1980s followed up by revealing other exotica: gamma-ray bursts, infrared galaxies, superluminal sources, gravitational lenses, and phenomena associated with the perplexing SS-433 and Geminga sources.

In the 1960s, astronomical work was relatively inexpensive, and U.S. astronomers, with the largest ground-based telescopes in existence, led the world in optical astronomy. We also had undisputed leadership in X-ray and infrared astronomy, and supported a strong community of radio astronomers and theorists. Much of that has changed. We still have strong participation in all those areas, but other nations have fielded impressive teams. Last year saw the launch of a powerful X-ray telescope, ROSAT, built by Germany with British and U.S. participation. Earlier, the Japanese had erected the large Nobeyama submillimeter radio telescope, and a French-German partnership had emplaced the Institut de Radio-Astronomie Millimétrique telescope in Spain. Similarly, neutrino astronomy was once the sole domain of Americans, but now Canada's Sudbury facility, Italy's Gran Sasso installation, Japan's Kamiokande detector, and the Soviet Union's SAGE experiment have some of the most powerful instruments in the field. As advances in science require increasingly sophisticated and more expensive telescopes and equipment as well as sizeable communities of astronomers, can the United States afford to compete in every research area?

The answer to such questions requires a national consensus. A recent two-year survey by a committee of 15 distinguished astronomers, headed by John N. Bahcall, director of the astrophysics program at the Princeton Institute for Advanced Studies, has just laid out the field's master plan for the 1990s. The committee drew from a broad segment of the astronomical community so that ultimately about one U.S. astronomer in every six was able to voice an opinion and help forge the plan.

The current bleak financial picture sets the tone for the report, but much to its credit, the committee came up with a balanced program of first-rate research. It calls for one truly sparkling, major space astrophysics mission: the Space Infrared

It's time for the astronomical community to pause and think about where it is headed.

Telescope Facility. Its other goals include two giant telescopes with collecting optics eight meters (26 feet) in diameter, an array of millimeter-wavelength telescopes working in concert, and a selection of moderate programs employing both space- and ground-based instruments.

For ground-based research, the report assigns highest priority to supporting the field's infrastructure and to the growth of research grants. Operations and maintenance at U.S. observatories have suffered to a point where the facilities have fallen into disrepair. During the 1980s, operating budgets of the observatories dropped by 20 to 35 percent and staffing levels declined by more than 15 percent. Meanwhile, research grants to young astronomers have suffered a decline stemming from the report's single most startling finding: between 1980 and 1990 the number of active astronomers in the United States grew by 42 percent.

Mindful of current tight federal budgets, the report nevertheless recommends an expansion of research grants, one aim being the support of graduate students and young postdoctoral researchers—a reasonable request, if the goal is further expansion of the field. But does this request imply the need for an equal growth in the number of astronomers during the 1990s? How large a growth rate should be encouraged? How many astronomers and how much research can the nation responsibly support?

In a recent interview given to MIT's *Technology Review,* Robert M. White, president of the National Academy of Engineering, outspokenly raises such issues. "[W]e appear to have too many scientists and engineers chasing too few research dollars," he said. "[A]re there too many scientists and engineers, or is there too little money?… It is not sufficient to claim entitlement to as much money as is necessary to support every good scientist…. Science and engineering research, like any other activity in this country, has a social purpose, and it must justify expenditures in ways that can be understood and lead to the social and economic betterment of the country."

This is an important message for all of us in astronomy. The discipline could find a way out of its current difficulties in two steps. First, we should acknowledge that the United States does not have the resources to maintain a global lead on all fronts. That would be a painful acknowledgment for many. But when other countries carry out a type of research, we could make cuts here while arranging international collaborations so that some of the most productive U.S. astronomers would be able to remain active in the field.

Between 1980 and 1990 the number of active astronomers in the United States grew by 42 percent.

Second, we should encourage young doctoral workers to move into industry. It makes no sense to have a rapidly growing astronomical community when industrial and government laboratories often are desperate for highly trained physical scientists with the skills young astronomers possess. Some Ph.D.'s in astronomy and astrophysics already are finding employment in industry. But the number remaining in basic research is increasing, and those continuing up the academic ladder are expected to attract and train the next generation of Ph.D. astronomers, accelerating growth of the nation's astronomer pool.

As we wrestle with priorities in the decade ahead, we will need to address the field's phenomenal successes and the rapid growth they fostered. The Bahcall report, as it will undoubtedly come to be known among astronomers, will be a great help, because it defines a set of priorities agreed on by leading members of the field. The astronomical community now needs to see how such a program can be implemented under existing financial exigencies. That will be a tough order, but it will allow us to peel away layers of uncertainty, peering back into the history of the universe so that our civilization can glimpse the beginnings of time and the moment of creation.

SURVEYOR *of the* UNIVERSE

When Margaret Geller took a look at the cosmos, she saw what no one had seen before.

by Andrew Chaikin

One by one the galaxies appear, like grains of salt on a velvet tablecloth. Now dozens become hundreds, then thousands, and slowly signs of order begin to emerge. As the camera pulls back, we see that the galaxies are arranged in a kind of pattern resembling, of all things, soap bubbles. Suddenly, the music swells into a processional and the cosmos executes a pirouette, almost as if it were showing off its grand inscrutability. We barely have time to register the impact when we find ourselves on a cosmic toboggan ride, darting among clusters of galaxies and zooming inward at fantastic speed, until out of the blackness appears our own blue and white, cloud-swept world.

The eight-minute video, entitled *Where the Galaxies Are,* is Margaret Geller's first effort at filmmaking. But in at least one respect, Geller, 43, brings to the craft more preparation than most novices: she has been investigating her subject for more than two decades. Today she has her name on one of the most profound scientific undertakings of our time—the mapping of the universe. Not since Edwin Hubble discovered the existence of other galaxies almost 70 years ago has astronomy so fundamentally changed our understanding of the cosmos.

SUSAN LAPIDES

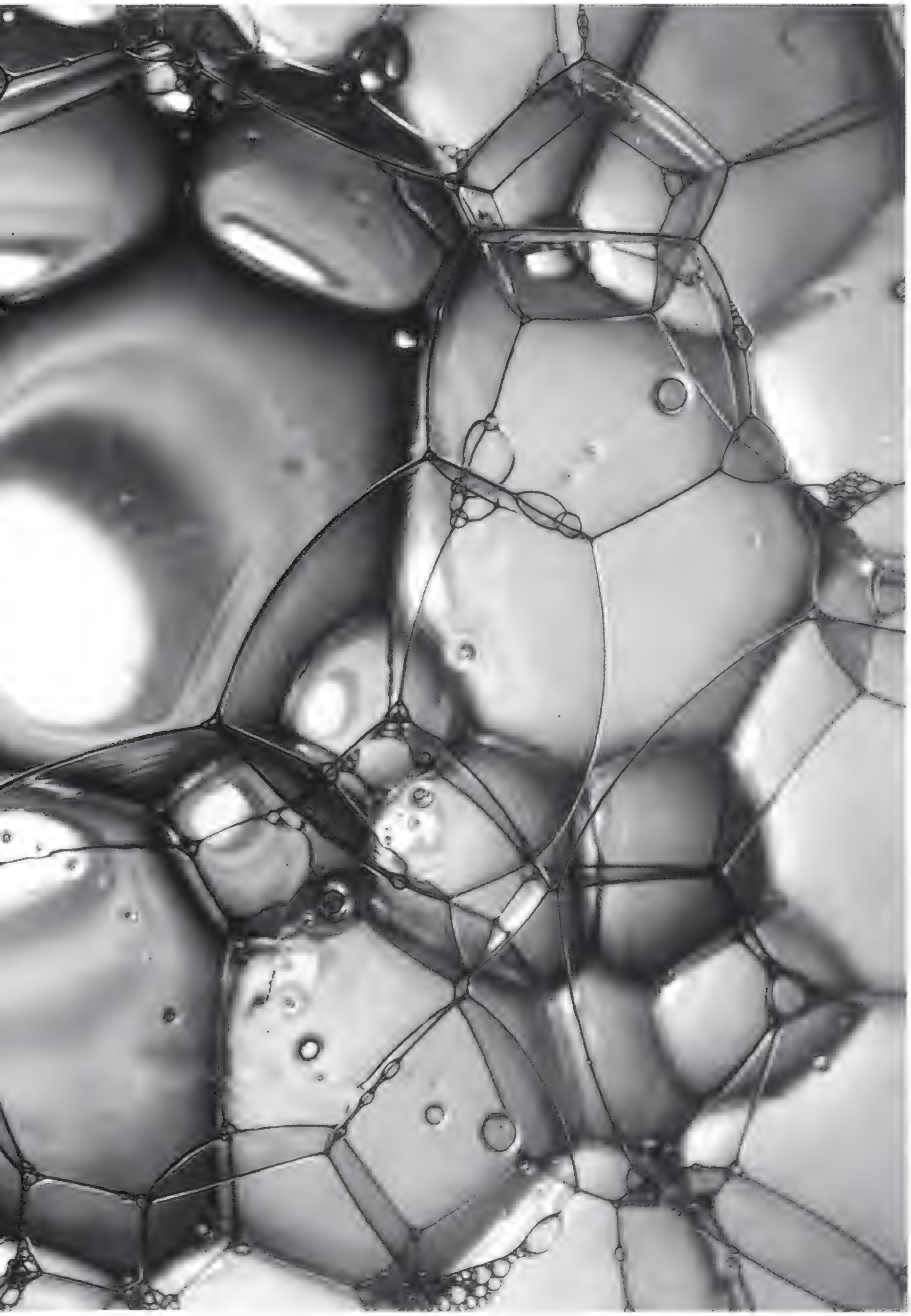
Margaret Geller has brought to the field of cosmology an uncommon knack for discerning patterns.

Since the late 1970s, Geller's colleagues at the Harvard-Smithsonian Center for Astrophysics in Massachusetts have been using a 60-inch reflecting telescope at Mount Hopkins in Arizona to painstakingly chart the positions of close to 12,000 galaxies stretching 500 million light years across space. From the beginning, the project, known as the Redshift Survey, has yielded tantalizing results: when the first 2,000 galaxies were mapped, the resulting picture showed them arranged in what appeared to be large filaments spanning across empty spaces. But this discovery, like other similar findings, was too limited in scope to overturn the astronomical orthodoxy that the universe was uniform in its overall structure.

In 1985 Geller and colleague John Huchra embarked on an extension of the original Redshift Survey that would penetrate twice as far into space. Believing that their large-scale inspection would reveal nothing more than a fairly even distribution of galaxies, the astronomers waited until their observations were completed before handing graduate student Valérie de Lapparent the numerical data to transform into visual representations.

When de Lapparent first beheld the galaxies' configurations, she didn't realize what she was seeing. She showed the plot to Huchra, whose first reaction was that he'd made a horrible mistake in collecting the data. Instead of being distributed consistently, the galaxies appeared to surround immense empty spaces the way soap film arranges itself in bubbles.

When she saw the patterns, Geller reacted differently from her collaborators. She was astounded. Not for a



BERENICE ABBOTT COMMERCE GRAPHICS LTD., INC

Geller is inspired by the photography of Berenice Abbott, whose portrayal of bubbles shows an appreciation of the elaborate designs nature creates.

moment did she doubt that the pattern was real.

Today, Geller vividly recalls the moment she felt what most scientists can hope to experience only once or perhaps twice in a lifetime—the thrill of a major discovery. "You really feel this thing: 'Why should we, out of all the people in the world, be the first three people to see this?' "

The answer, in part, is simply that the extended Redshift Survey has been far more comprehensive than earlier, less revealing mapping efforts. But perhaps just as important, the undertaking has had the benefit of Geller's deep affinity for the visual.

The Redshift Survey is based on Edwin Hubble's 1929 observation that distant galaxies appear to be speeding away at fantastic speeds. In that finding lay the foundation of modern cosmology: the universe is expanding in the wake of its fiery, explosive birth, known as the Big Bang.

The key to Hubble's finding was the effect astronomers call redshift, in which the tremendous velocity of the universe's expansion stretches out the light from fleeing galaxies and makes it appear redder. The farther away a galaxy is, the faster it moves—and consequently, the more its light shifts to the red end of the spectrum. To determine a galaxy's distance, one need only measure its redshift by photographing and analyzing its spectrum. That, combined with the galaxy's location in the sky, essentially identifies its actual position in space.

But in Hubble's time, and for decades afterwards, a redshift survey like Geller and Huchra's was all but impossible. Even with the largest telescopes, it took hours to acquire the spectrum necessary to determine a single galaxy's redshift. In the 1970s, the introduction of sensitive solid-state detectors finally enabled researchers to do the same thing in half an hour, using far smaller telescopes.

When the results of the first large-scale redshift surveys started coming in, they seemed to contradict the conventional wisdom about the universe's structure. According to classic Big Bang theory, shortly after its birth, the universe was uniformly filled with hydrogen gas; the distribution of galaxies ultimately formed from that gas should therefore be equally uniform. "I remember the vision of the extragalactic world that I got as a grad student was that things were basically uniform as long as you looked on a sufficiently large scale," says Richard Kron, director of the University of Chicago's Yerkes Observatory. "There was this optimism that 'sufficiently large scale' was right around the corner."

But in the last decade, astronomers have become more receptive to the notion that the universe is patterned, thanks in part to the Redshift Survey—and in particular to Geller's insistence on seeing the data rendered visually. "The conventional way of analyzing the galaxy distribution focuses on statistics," says Edwin Turner, an astronomer at Princeton University. "So you could imagine mapping some new continent and instead of sending back a map, you

report back: 'There are so many islands and so many rivers of such and such a length....' I think there are some [astronomers] who might not have even bothered to make the picture."

Geller not only made the picture; she instinctively trusted it. "I think we're wired up to react to these natural patterns," she says. "We're wired up so that we think they're beautiful. And we're also wired up to be able to understand them."

How, then, are we to understand the patterns the Redshift Survey has revealed? Many astronomers believe that gravity alone causes galaxies to cluster together, but Geller and Huchra's bubbles suggest a different force: shock waves. According to a scenario independently proposed by astrophysicists at Princeton and in Japan, shortly after its formation, the universe may have been racked by a series of explosions, perhaps caused by the deaths of the first generations of stars. The massive shock waves resulting from the explosions dispersed all matter in their paths into shells. When neighboring shells collided, matter was compressed and galaxies began to form. The result—a skyful of galaxies resembling soapsuds.

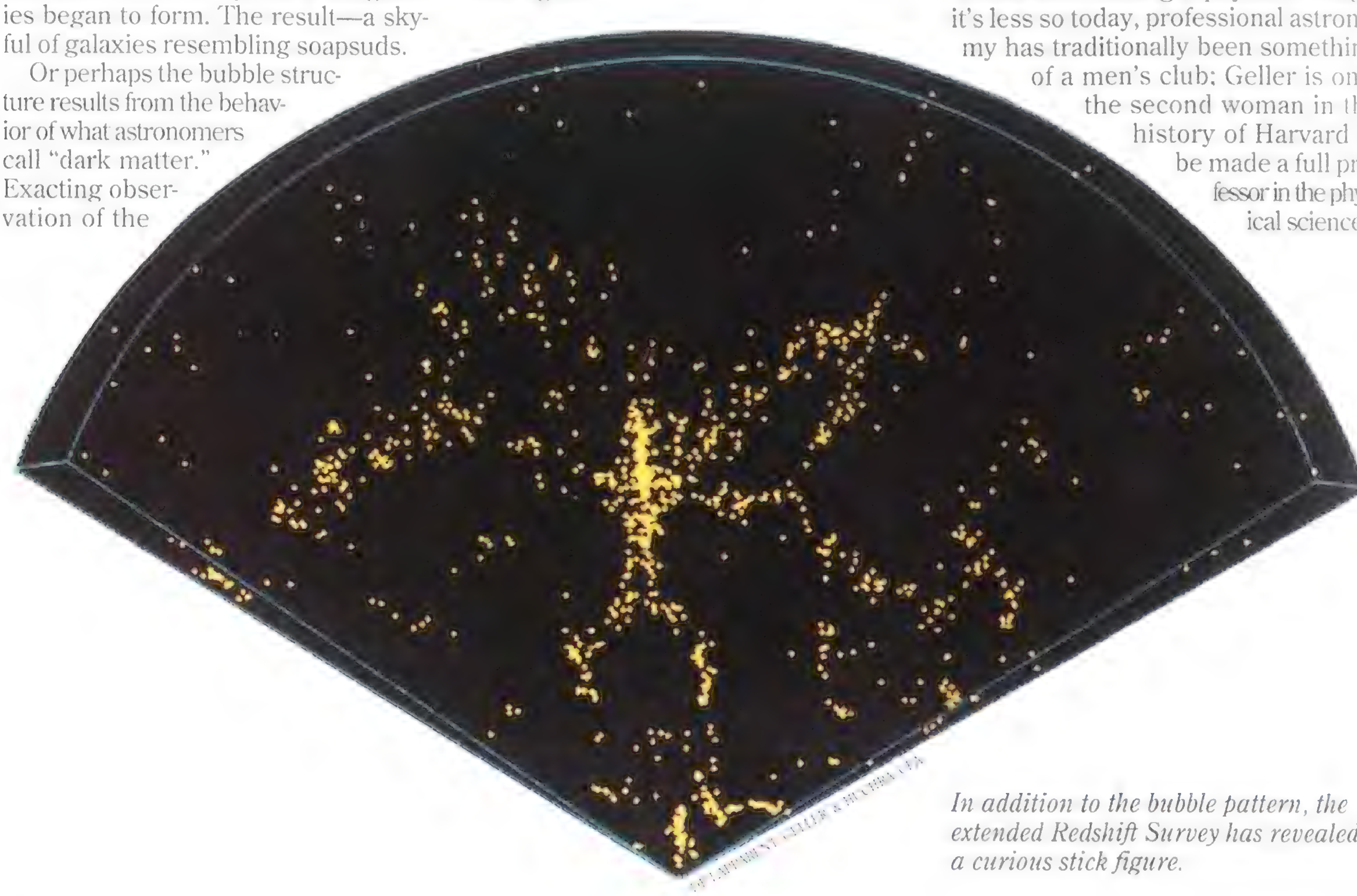
Or perhaps the bubble structure results from the behavior of what astronomers call "dark matter." Exacting observation of the movements of stars and galaxies has suggested that the universe has far more mass than astronomers have so far accounted for. Today, many believe that this missing mass makes up nine-tenths or more of the stuff of Creation. If the universe is really full of dark matter, the voids of the map—the insides of the bubbles—may not be empty at all. The galaxies themselves, says Geller, may be nothing more than foam on the waves of a vast, invisible ocean.

"I've always liked to look at things," Geller says today. "I like patterns." The view from her office window is of bare December trees; sometimes Geller looks out at them and contemplates the branching patterns, big limbs forking into smaller ones, which in turn stretch countless smaller woody fingers against the sky. In one moment they resemble tributaries of a great river seen from the air; in another, capillaries seen under a microscope. "It's the same," Geller says. "You have to transport fluids around. It's remarkable how nature makes these patterns again and again and again."

The fascination with patterns came from her father, a crystallographer at Bell Laboratories who probed the unseen world of atomic structures. In his impromptu science lessons, Margaret learned to look at a crystal of salt and see a cube, and she discovered the myriad shapes nature uses to create order, from pyramids to icosahedrons. Growing up, she came to see the artist in her father as well: in his spare time he designed and built furniture. As a child Margaret considered a career in furniture or fashion design, but gave up on those ideas because she couldn't really draw.

Visiting Bell labs, then in its glory days, she found she enjoyed the world of the professional scientist. Encouraged by her father, Geller ended up studying physics at Berkeley. Though she came close to pursuing a career in her father's area, solid-state physics, she finally settled on astrophysics, a field alive with new ideas and the possibility of new discoveries.

When she went to Princeton in 1970 to work toward a doctorate, Geller faced professors who told her bluntly that women didn't belong in physics. Though it's less so today, professional astronomy has traditionally been something of a men's club; Geller is only the second woman in the history of Harvard to be made a full professor in the physical sciences.



In addition to the bubble pattern, the extended Redshift Survey has revealed a curious stick figure.

"Women in science...because it's a nontraditional field for women, have to be the type of people who are willing to take chances and move outside the beaten track," observes Princeton's Edwin Turner.

Throughout her career, Geller has had to contend with other damaging perceptions of science, such as the pervasive public notion that science must be impenetrably obscure. To help change that thinking, Geller has delivered lectures on astronomy for lay audiences and appeared frequently on television news shows and documentaries.

Venturing from one side of the camera to the other to make her video, Geller was initially apprehensive. But she found the experience of filmmaking has a lot in common with science. "It's excruciating work," she says. "Most of science is drudge; most of making films is drudge." But Geller the filmmaker had to do something that Geller the scientist never does: she had to use her emotions in her work. One such moment occurred while she listened to composer Guy van Duser's first suggestions for a background score. "It didn't say the right thing," she recalls, "so in my feeble way I tried to say that it had to be grand, but it also had to have a delicacy; this was what I felt. And I'm talking about a scientific image. But this is how I wanted it to *feel.* Now normally people do not talk about how they want their data to feel."

Tapping her emotions has paid off. "You look at the faces of the people watching [the video] and you see they feel something," Geller says. "And you think, *My God, this is our goal—to make people* feel *something about science, and not just to have it dry, and to rouse their emotions. And we did it!"*

Though not without some compromises. The computer-generated cosmic zoom among the galaxies, for example, is breathtaking, but a real camera filming such footage would have to travel far in excess of the speed of light, Einstein's universal speed limit. Though Geller is satisfied with the film's visual and emotional impact, she recognizes its limitations: "People have asked me, Am I going to show it here at the observatory? I feel reluctant because it isn't science. And within the observatory I want to be known for my science."

SUSAN LAPIDES

Redshift Survey veteran John Huchra has been racking up provocative observations of galaxies since 1978.

A scientist who becomes a science popularizer often becomes a target of disdain from other researchers. Cinematographer Boyd Estus, who collaborated with Geller on *Where the Galaxies Are,* sees that constantly: "You go into a university department to film a 'Nova' [TV series episode] and there's all that sniping: 'So-and-so is a star today.' You know those people would give their eyeteeth to be on 'Nova.' " When Geller began to sense that attitude among her peers, she turned to astronomy popularizer Carl Sagan for advice. "He essentially said, 'Do what you want to do and don't worry—your friends will be your friends no matter what, and your enemies will be your enemies no matter what,' " she recalls.

Whatever friction her popularizing has caused among her colleagues, Geller is getting encouragement elsewhere. Last year, the multidisciplinary MacArthur Foundation gave her one of its famous "genius grants"—a five-year, $265,000 endowment that she is free to use however she pleases. The award has opened up a number of compelling opportunities, such as writing books and making more films. Geller and Estus are going ahead with an idea that was already in the works, a documentary on the scientists of the Redshift Survey. "I feel a little guilty," Geller says. "I feel I'm supposed to be doing scientific research, and of course I am. But I feel very torn. All of a sudden I have opportunities to do these kind of things which have always fascinated me."

Geller's friend Edwin Turner understands her temptations. Geller, he observes, is not "an extremely methodical person in her research, who lays out a carefully conceived long-range plan and then executes it.... She's much more of an exploiter of openings, a follower of opportunities."

Geller has reached that stage in her career when many scientists start moving into administrative positions, but she feels she just isn't cut out for the committee room. "I'm very impatient," she says. "I start making faces; everybody knows. I'm really awful." She'd also find it very difficult to give up hands-on research. "When you're out there, you want to stay because it's exciting. It's kind of like a drug. And you want more.

"There are people who produce exciting things throughout their lives," she says, "and I hope that I'm going to be like that." Geller takes inspiration from photographer Berenice Abbott, who chronicled the lives of writers and artists in Paris in the 1920s, portrayed New York City in the '30s, and then, in the '50s, answered a new calling: documenting the beauty of physics. Her photographs capture the elegance of everyday phenomena—light beams bending within a prism, a multiple-exposed wrench spinning around a fixed point. Soap bubbles.

The only significant thing Geller has done with her MacArthur money so far has been to take a trip to Maine to visit Abbott. "It was an unbelievable experience," Geller recalls. "Here's this woman who's 92 years old and you'd almost think she'd get up and start taking photographs. She's so alive and curious about the world around her—that's what keeps her alive—so eager to talk and to tell about what she saw.

"She had a lot of courage to try to do the things that she wanted to do, regardless of whether she got the support for them at the time or not," Geller continues. It's this confidence that most impresses the astronomer: "It might sound very egotistical to say this, but I think that I will do other things that will have substantial impact, whether it be other things in science, or whether it be something completely different." These days Margaret Geller talks like someone whose life is an open door. And she says, "I have this habit that when doors open I like to walk through them."

World War II's Flying Colors

Photographed by soldiers and airmen and stored away in attics, early color images are casting new light on airbase life.

WILLIAM J. SKINNER

by Jeffrey L. Ethell

For most of us, our impressions shaped by famous images of the era, World War II was a conflict fought in black and white.

As a history writer specializing in wartime aviation, I had long been aware that only a very small amount of color photography of the war existed. For instance, less than two percent of the National Air and Space Museum's collection of World War II photographs is in color. Over the years these few images have been reproduced repeatedly to show readers what a P-51 or B-17 looked like in warpaint.

I was never content with this. In my father's scrapbook from his Army Air Forces days there was a single color slide, a wonderful shot of him sitting on the wing of his silver P-51D Mustang with its red, white, and blue tail. Spread across the nose in red was the name of my mother, Jeanie, with her portrait below.

As a youngster, I'd stared at that slide for hours on end, intrigued by the glimpse it gave me into a part of my father's life I otherwise couldn't have known. Dad still has no idea where he got the slide; the remainder of his photographs, like most of the photos and newsreels of the day, were shot in black and white.

Color film—Kodak's Kodachrome—had been introduced in 1936, but the vast majority of professional photographers and

ROBERT T. SAND

USAF NASM

ROBERT T. SAND

Photojournalists captured World War II largely in black and white; the color photography of the era was mostly produced by soldiers who more often documented quiet, private moments rather than big, newsmaking events: the sky's odd beauty before a mission (far left), fighter pilots in front of their mess hall (inset), writing home from England (above), and a favorite pilots' pastime (left).

The pilots' beloved A-2 leather jackets still look unblemished in a pre-mission operations meeting (right). On its way home from battle, a a B-17 shows its scars (below).

HERBERT R. RUTLAND JR.

"It was like a knife in the heart," a fighter pilot wrote about watching German civilians demolish American P-51s after the war.

MARK H. BROWN, USAFA

ROBERT T. SAND

Nose art was a popular subject for the amateur WWII photographer; Bob Sand, who took this shot of the P-38 Mountain Ayers, *was also the artist.*

photojournalists, while fascinated with its potential, had little choice then but to ignore it. The film was "slow," requiring longer exposure times that were ill-suited for shooting action. It didn't store well either, and, most troublesome of all, it required a delicate developing process with precise temperature controls; at the time, Kodak's plant in Rochester, New York, was the only facility that could handle it.

"A field photographer wanted something he could develop in his tent at night," says Phil Condax, senior curator for technology collections at the International Museum of Photography at George Eastman House in Rochester. "They didn't have the luxury of waiting weeks for film to be shipped to Rochester and back."

The majority of World War II color photographs, therefore, were taken by what Condax calls "*interested* amateurs." Interested because, while the constraints that hobbled professionals were less troubling to amateurs, the film was in short supply due to wartime production rates, and it could take diligent effort to find it.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As I returned again and again to Dad's color slide, I began to realize that there had to be many others like it out there—that a wealth of World War II color photography likely lay scattered across the country, in the shoe boxes, attics, and photo albums of private collections.

For about 15 years, whenever I contacted a likely source, I made a habit of asking for color photographs. Soon slides began to trickle in, almost all from personal collections. The dam finally burst when, through a series of contacts with the P-38 National Association and the 55th Fighter Group Association, I found Bob Sand. When I saw his slides, I knew I was on to something special.

Bob had been stationed in England as a P-38 propeller specialist and then a P-51 crew chief. When he arrived in 1943 he was so impressed with the rich colors of the countryside that he wrote his parents asking for a camera and color film. His father found a cheap Kodak Bantam and two rolls of Kodachrome, and shipped them off to England. On Thanksgiving 1943, Bob wrote home: "I've shot up one roll of film and while this roll contains nothing spectacular, I hope it is the beginning of something that may have a little interest later on." Every few weeks for the duration of the war, Bob would receive one or two rolls from his parents or friends. By the end of the war he had more than 430 color images of life on a wartime fighter base.

WILLIAM J. SKINNER

USAF/NASM

When Mt. Vesuvius erupted in March 1944, its casualties included the 340th Bomb Group's B-25s, stationed near Pompeii.

This mascot for a squadron based in Britain looks suitably Churchillian. In fact, its sire belonged to the prime minister.

Flecked with light filtered through camouflage netting, a bomb dump resembles a pointillist painting (left).

As usual, Bob Hope took a back seat to the pretty women in his USO show. "Gee, they looked good!" photographer Bob Sand recalled.

ROBERT T. SAND

Pre-mission preparations completed, a ground crew awaits the Spitfire's pilot.

My hundreds of letters turned up other fruitful sources. With World War II upon him, budding professional photographer Cal Sloan had enlisted and shipped out to England with the 1066th Signal Company, attached to the 355th Fighter Group. He had his wife send his Zeiss Contax 35mm over, and she bought and mailed what Kodachrome she could find, one or two rolls at a time. Cal ended up with more than 200 images, each shot with careful precision using a Weston light meter. "I had an eye for this," he recalls. "I wanted to shoot for the future, to create a record of what I was seeing."

Future Spitfire pilot Bill Skinner was working for a camera store in 1938 when he bought his first Kodak Bantam for $25. By the time he was flying with the 31st Fighter Group in North Africa, Sicily, and southern Italy, his mother had sent him a Bantam Special. When she could find it, she shipped Kodachrome off to him four or five rolls at a time. Bill sent his exposed rolls home with guys rotating back to the States and, like many servicemen shooting color film, didn't see the results until he returned himself. "If I'd known how good I was doing, I'd have taken more," he says.

As a photographer for Acme News Pictures, Fred Bamberger discovered 35mm color film for his Contax when it first became available. After joining the Army, he went overseas with the 90th Photo

U.S. Army Air Forces cadets got their first real feel of power in AT-6 trainers (right). Some took such delight in it that they buzzed local towns.

WILLIAM J. SKINNER

USAF

Reconnaissance Wing. As photo officer for the 12th Air Force in Italy, he had an unlimited pass to take his camera wherever he wanted, and he shot close to 1,500 Kodachrome slides while off duty.

Eventually I received thousands of photographs from dozens of people—enough to fill two books. (The first, *Fighter Command: American Fighters in Original WWII Color*, co-authored with Bob Sand, has just been published by Motorbooks International.) Some of the photographs were parts of large collections; others were from individuals who'd only been able to obtain a roll or two of color film.

Because these photographs represent part of the rare color record of the war, calling them snapshots may seem a slight. Yet that is exactly what many of them are: tourist shots, taken by guys who for the most part had never before been overseas. Indeed, the slides owe much to these humble origins, for they've managed to capture ordinary life on War War II bases. These images will color our perceptions and memories of this war for a long time to come.

USAF NASM

American ace Francis "Gabby" Gabreski—cloaked in British gear, which pilots found more comfortable—scored 28 aerial victories in the war.

Why We Fly

Essentially, an airplane is a way of getting from here to there, like a car. It is simply a conveyance, a machine—more or less comfortable, rapid and costly as the case may be, but nothing more, really, than a fast bus. You get aboard, fire it up, and sit it out. Nothing more to it.

Or is there? Indeed, there must be something special about airplanes—you can tell by the people who fly them. Not that there is anything special about pilots before they become pilots; like everybody else, they are for the most part quite ordinary people. Airplane manufacturers advertise that anyone can do it (while pilots try to convey the impression, tacitly or explicitly, that *not* anyone can). Again, it's like driving a car; everyone can do it, except for a few who for one reason or another can't quite. And yet you never see someone at a cocktail party casually drop mention of having *driven* here or there in the confident (and rarely disappointed) expectation of an apotheosis. Everyone drives; no one is impressed. Few fly, and lots of people are impressed—not least among them the fliers themselves.

Flying becomes the hallmark of the people who do it. Whatever else they are, they are pilots, and among other pilots they always find themselves at home, however little they may otherwise have in common. Some become incapable of talking about any subject other than flying; they long to bring the conversation around to airplanes, and when they get it there they are loath to see it move on. They are in thrall to some element of the aviator's experience that acts upon them like a narcotic upon an addict. And addicts they are—genuine addicts, who have let marriages founder and careers pass them by because the spell of an airplane was too hard to break and the possibility of a chance to get behind the controls of an airplane again too precious to be passed up for something else. The aviator's experience, whatever it is, is a profound one that enters dim and out-of-touch recesses of the soul.

The explanations they usually give seem hollow. Gee, it's just great putt-putting around up there where never lark nor even eagle flew, swooping around, dancing with the clouds, great sense of freedom, touch the face of God, liberty, helluva feeling. Is that really it? For many people the cockpit of an airplane is the antithesis of freedom; a tiny cell suspended in space, a very metaphor of al that is unsure and terrifying in the huma condition. Some are haunted by the thought of the fall. For others, the boredom of it all beggars imagining. How can it be, pilot, that you are so blissful when others quake or yawn? Or are you blissful? Are there not many pilots who, if they had it out with themselves, would have to admit that they don't really particularly *like* flying, that it isn't fun for them the way playing ball or swimming or even watching TV is fun? Who would have to admit that they have many a time forgiven the vacuity of one flight with the facile reflection that the

ROSEMARY HENRY-M

next one will be different?

Yet they don't have it out with themselves, and despite the cost and the inconvenience and the noisiness and the crowding and the immobility they fly, and in the balance, when all their assets and liabilities are spun out in the centrifuge of some last judgment, they have not lost. But not because they have wheeled with eagles (an eagle passes an airplane looking like a paper bag falling past a tenth-story window) and not because they have danced with clouds (a cloud is a turbulent pudding as big as a mountain and one cannot dance with it; anyway an airplane cannot dance, but only lunge in slow motion). Because of something else.

Flying is a symbol. It is a symbol in a broad, historical sense—a Jungian archetype in good standing, a vision to which we all resonate in unison, whatever the age or place or time of birth. Remember the hawk-like man, Daedalus? He was your interesting, romantic flyer, a real cliché; cunning, egotistical, and though he had a son who went about with him, he was not much of a father. He was too busy with his inventions and his contracts. The boy Icarus was headstrong and isolated, wouldn't listen to instructions, couldn't take orders or even a piece of good advice. When in the course of a jailbreak Icarus fell to his death in the sea, Daedalus, cold soul with a head full of bitter ideas, must have breathed a silent curse, closed his mind, and flapped on.

Flight is jailbreak. It is also cunning and indifference, the virtues of wolves.

There is, too, a special perspective to it, both within and without. In the midst of games, talking, walking on the beach, one looks up and is spellbound by the silent arrowhead of a jet sliding by so far off, almost on the edge of space. It is hypnotic in its separateness, peaceful in its mysterious purpose, splendid in its simplicity and sureness, like a lone hawk hanging over a hill. And if the ideal of philosophic thought was once to see in the mind, in a crystal instant, all life and matter rolled up into a ball as astronauts saw it rise over the horizon of the moon, then a pilot's hours are a string of such instants, looking down on the immobile earth, all come at once to the eye—towns and streams and highways and rails, all human life encompassed and mapped, ready to be understood as we understand what we hold in our hand. Earth and the flier regard one another in a kind of mutual perception, in its best moments something like love.

The love colors all your memories. If you have traveled not by car or train but

by airplane, you have not seen tunnels, halls, and tables through and across which you crept or sped, but rather a tapestry rich in detail, myriad in its textures and colorings, vast as the horizons and vaster still, and heartless and peaceful as a sleeper's face. You have swept across interminable fields that fanned past you like a spinning parasol, and hung in roaring stillness while the arcing line of night, like a monk's cowl, swung down overhead to quash before your eyes the last crescent of the day. You have flown through submarine caverns in which hanging gardens of mist and cloud turned blue-gray in the evening; over rusting deserts where an impeccable sun rose slowly over utter lifelessness; down valleys where shreds of cloud reached toward you from the backs of the windward hills; among thunderclouds whose miles-high cliffs boiling and swirling on both sides of you let no sunbeams enter. In a Texas dawn you saw a grain elevator whose shadow stretched 80 miles to the horizon. If you miss anything when you die, it will be the glow of instrument dials in the darkness; the blissful sunrise; the long, hot, stormy afternoon; the calm and sadness and slowness of evening; the world as carpet, map, model railroad, standing at a remove from you, tinged and enveloped by the delight and melancholy of your own isolation.

Flight is knowledge and power. It is something other people can't do. That is, in fact, the vile part of it: that trivial vanity, sometimes unconscious but often uncomfortably self-aware, that suffuses the pilot's motions as he starts the engines under the silent, mystified eyes of his passengers. He is a magician, a fabulous artificer, taking you where you want to go, looking down on mundane concerns with a calm and detached eye, soaring philosopher, manipulating with nonchalance the instruments and controls which the layman dares not even brush with a careless cuff. It's a hard pride to give up, and many pilots find it difficult to teach their spouses to fly. It is not to the advantage of heroes for the true nature of courage to become public knowledge.

The love of flying is not without its infantile aspects; but there is more to it than that. Flight is quintessentially a symbol of human ambition and daring, of the application of skill and intelligence to problems that seem to defy solution. While it has long since ceased to require either particular skill or daring, the art of piloting still glows with some remnants of the heat of its conception. Few pilots—few people, in fact—are insensible of this special aura, and it becomes in those who bask in its warmth a powerful agency, like money, of good or ill. There are many to whom it is only a sop to conceit, an empty snobbery, something to flaunt before strangers. But to the better it is like the great traditions of old craftsmen; a touchstone for inner growth, a blessing of which one must make oneself worthy, a kind of privilege that should inspire modesty. *Noblesse oblige.*

The remarkable thing about people who fly is not that they are so clever; it's that they are so lucky. The clever ones realize it, and even the least perspicacious catch some spark of a hint of their good fortune. It's what keeps them going despite poverty, divorce, and bad horoscopes. Sometimes it keeps them going despite bad weather as well, and that is the dangerous side of the matter: the sirens' song to which few can stop their ears. The most difficult of the pilot's arts is that of knowing when not to fly. It is also the last test of the real pilot; for if flying is cunning and mastery, it is good sense and self-mastery as well. Until a pilot has learned to transcend the faint glory that shines through flight and subordinate it to his own will, he has still not learned the most essential part of imitating birds: that birds fly because it is natural to do so, not because they admire themselves for doing so. Flying can transform a life from sheer plod to riding high; it can also be a cul de sac at the end of which a lot of bores sit talking at one another about their old experiences. Of all the risks that the joy of flying requires, that of falling prey to the misuse of it is the greatest of all.

—Peter Garrison

Barons of the Sky: From Early Flight to Strategic Warfare. The Story of the American Aerospace Industry *by Wayne Biddle. Simon and Schuster, 1991. 358 pp., b&w photos, $22.95 (hardbound).*

Early flying lore used to fall in the *Aviation Book for Boys* mode. Every airplane, every flight was a noble achievement, and the people who built airplanes and flew them were eagle-eyed, square-jawed heroes. The good news about *Air & Space/Smithsonian* contributor Wayne Biddle's new book is that it takes a much more realistic look at some of the pioneers of the enormous, controversial, and sometimes prosperous aerospace industry.

"Sometimes" is the operative word; in its early days, aircraft manufacturing was synonymous with hard times. As a boy, John Northrop lived in a tent with his family when they migrated to California with hardly a nickel. As an airplane designer without an engineering degree, he barely hung on until his luck turned. Donald Douglas had more than a nickel in his pocket—but not much more—when he broke away from Glenn Martin and headed west also. Getting Douglas Aircraft financed, even with a Navy contract in hand, meant swimming into the tentacles of *Los Angeles Times* publisher and speculator Harry Chandler. Robert Gross picked up the remnants of the Loughead company—later, phonetically, "Lockheed"—at a bankruptcy sale. Though born into New England wealth, he barely stayed afloat in the Depression.

Yet even in the grim 1930s, some found the means to prosper. Glenn Martin, the son of a country hardware store clerk, had the instincts of a circus pitchman along with an innate sense of how to manipulate a dollar. Prim and something of a mama's boy, he never took a wife. But he lived high, driving a Stutz and escaping from Baltimore's muggy summer to his mansion in California. Meanwhile, his company skated through the Depression with a government Reconstruction Finance Corporation bailout. And Donald Douglas, whose prosperous company afforded him weekend parties aboard his yacht, took both a wife and an apartment for a favorite lady.

As a tough look at the business shenanigans of the early aviation industry, *Barons of the Sky* is fascinating. It is so well crafted that it flows like rich cream.

Those of us who grew up in the Depression as unrealistic and starry-eyed about airplanes as the aircraft founding fathers were, however, will bridle at the book's central thesis. There's no question that aviation depended on military money to survive and grow. But those who lasted through World War II because of this industry, then watched peace come undone with the Soviets' blockade of Berlin, are going to wonder at Biddle's assertion that his barons were little more than profiteers whose real legacy was a ruthless weapons industry. Was the Finletter Commission, appointed by President Truman in 1947 to study the postwar aviation industry, simply a self-serving panel of businessmen and bureaucrats that "laid the foundations for a Cold War armaments industry," as Biddle asserts? Was the Soviet threat merely "a catch-all justification for rearmament" in the decades after World War II? Was Hitler just another stuffed uniform?

Amid all that is a curious omission: Biddle virtually ignores Bill Boeing, whose legacy is a multibillion-dollar company that today does almost all its business with the airlines. And if Biddle wanted struggles of conscience, he could have turned to Igor Sikorsky, the visionary genius who always regretted the military role filled by the machine he had lavished his talent upon, the helicopter.

A couple of weeks ago, I spent an hour wandering through the early-years wing of the U.S. Air Force Museum at Wright-Patterson Air Force Base in Ohio. Sandwiched into the crowded hall was a Martin B-10, a bit-player in *Barons of the Sky.* Antiquated as the 1930s-era airplane looks now, the B-10 had fully cantilevered all-metal wings, retractable landing gear, and a speed equal to that of the first-line Air Corps fighters of the time. And it started a line that led to the Boeing B-17 and B-52.

Was the B-10 no more than another murderous weapon, the result of just another sole-source military contract wangled by a fast-buck operator more concerned with his company's survival than the Allies'? Biddle answers yes, and he makes a case for his interpretation. Maybe what we have here is a generation gap, or a case of half-empty versus half-full. My generation thinks helping to squash Adolf Hitler and run the Soviets out of gas was not a bad half-century's work for aviation.

—Formerly editor of Aviation Week & Space Technology, *William H. Gregory is the author of* The Defense Procurement Mess.

Ballooning: The Complete Guide to Riding the Winds *by Dick Wirth and Jerry Young. Random House, 1991. 168 pp., color and b&w photos, $22.50 (paper).*

Ballooning, an updated edition of a 1980 book, is filled with more hot air than a joint session of Congress—but that's the point. The writing about the sport is almost evangelical in its fervor: the beautiful photos indicate why.

Lonely Hearts of the Cosmos: The Story of the Scientific Quest for the Secret of the Universe *by Dennis Overbye. Harper Collins, 1991. 438 pp., b&w photos, $25 (hardbound).*

Cosmology, the study of the universe as a whole, is "an old pursuit, an ancient yearning, but it is not an old science," writes Dennis Overbye in this marvelous introduction to one of the most exciting branches of astronomy. Questions concerning the origin and structure of the universe passed from the realm of philosophical speculation to that of empirical science only recently. As Overbye writes, the discipline's "entire history to date could be compressed into a single human life span."

And it is with the lives of modern cosmologists that he is concerned. For five years Overbye has been interviewing them, attending their conferences, and peering over their shoulders—sometimes literally—as they worked. This book is a chronicle of what he saw.

With rare skill, Overbye explicates the scientific issues underlying the modern theory of the cosmos. The field began with what surely must be one of the great ironies of modern science. Albert Einstein's theory of general relativity, formulated in 1915, predicted that the cosmos must be expanding or contracting. But in 1915 astronomers thought the universe was composed solely of stars, which, according to the knowledge of the time, were flying neither away from nor toward us. So Einstein modified his theory to remove the unwanted prediction.

A decade later Edwin Hubble showed that stars are grouped into gigantic "island universes"—galaxies—that are, in fact, moving in just the way originally predicted by relativity. Einstein retracted his modification, calling it "the greatest blunder I ever committed in my life."

It seems to me that such a halting, back-and-forth process is normal in science. Bad books tend to present the story of scientific discovery as a steady progress toward the truth. Overbye, in contrast, skillfully chronicles what doing research is actually like. At the heart of his narrative are the cosmologists—people engaged in an endless struggle to push the limits of observation ever farther; people struggling to formulate theories, each more bizarre and extraordinary than the one before but none, it seems, bizarre enough. At times, particularly in his portrait of cosmologist Allan Sandage, Overbye's story rises to an electric intensity.

The book has a few minor problems. The title, for one, is foolish. At times Overbye invests developments with an importance they do not deserve, mistaking an exciting discovery for one of revolutionary significance. And most importantly, he seems unable to end his book; after winding on for more than 400 pages, it does not so much end as stop.

But I think I understand the origin of this last problem. For in fact Overbye's story has no end: the story he set himself to tell is a story in the making. Tomorrow will bring yet more exciting discoveries, yet more wonderful new theories, and, if the past is any guide, yet more transformations of our ideas. If you are looking for definitive conclusions about the origin and nature of the cosmos, you will not find them here. But if you are looking for the best we have to offer at the moment, and if you are looking for a picture of what it is actually like to dedicate one's life to this strange and marvelous struggle, I know of no book that does better than this.

—George Greenstein, author of The Symbiotic Universe, *is a professor of astronomy at Amherst College.*

The Aircraft Cockpit: From Stick-and-String to Fly-by-Wire *by L.F.E. Coombs. Patrick Stephens Limited (through Motorbooks International in the U.S.), 1991. 240 pp., b&w and color photos, $39.45 (hardbound).*

Get past that sense of dread by telling yourself, *Yes, this book really is a complete history of airplane cockpits, but then, how very timely!* For the hardcore buff, the sort of detail in this focused work can be rewarding, but those who are less concerned with whether a certain gangway was to the left or right of the pilot will have to do some skimming to find the more interesting tales of how cockpits came to be the way they are.

That's when the scholarly Coombs is at his best. He leads the reader skillfully and usually chronologically, beginning in an era when chaos, not design, determined such things as how instruments are grouped. Gradually science got involved, and some very bright people thought to record pilots' eye movements while they were flying. Out of such study came the arrangement of flight instruments, known as the basic T, that survives today. The book is brimful of stories revealing the roots of design concepts. Some may feel the treatment of human factors in the cockpit is the province of psychologists, not engineers, but the apparent frailty of the human being in the front office of an airplane does make headlines now and then, and Coombs' history connects tradition to modernity.

Pilots take note: buy this book and you'll win lots of arguments in bars. Non-pilots who read it will understand why bars are popular spots for pilots to argue.

—George C. Larson is the editor of Air & Space/Smithsonian.

Burner: Once a Blue Angel *directed by Paul Marlow, produced by Richard Russell and Paul Marlow. Threshold Releasing, Inc. (1-800-225-2376), 1991. 114 min., $42.95 (includes shipping).*

A nearly two-hour airshow, including great, giddy footage from BD-5J and F-4 cockpits. Country music! Forty-four inverted flat spins in a Pitts! Simulated bombing! Harrier! Thunderbirds! Somebody get me a cheeseburger!

Credits

In Memoriam. Jim Norris worked at Lockheed's Skunk Works for 10 years. An aerospace manager and writer, he is working on his third novel.

Terminal Fatigue. Ellis Weiner's last contribution to Flights & Fancy was "Spaced Out" (February/March 1991).

Doctor's Orders. Nancy Shute, a Washington, D.C.-based writer, contributes to *In Health*, *Smithsonian*, and *Special Reports/Health*.

The Floating World at Zero G. Doug Stewart is a writer living in Ipswich, Massachusetts. His last work for *Air & Space/Smithsonian* was "Satellite Sleuths" (June/July 1990).

"You Have Made Yourself Immortal." Lee Battaglia is the picture editor and Tom Huntington is the managing editor of *Air & Space/Smithsonian*.

License to Launch. Martin Morse Wooster is the Washington editor of *Reason* magazine.

Forecast: Liquid Helium Showers, Temperatures 290 Below Zero. The author of books about the sun and the space probes Viking and Voyager, Mark Washburn has been writing about planetary science for 15 years.

Satellite Saviors. Washington, D.C.-based writer Frank Kuznik first encountered a satellite in his own backyard. He remembers watching a bright light that his parents called Sputnik drift across the night sky.

Ballet Among the Clouds. An aerobatic pilot, Larry Lowe has been competing and judging for over a decade. He intends to be world champion.

Surveyor of the Universe. Andrew Chaikin is a freelance writer based in Arlington, Massachusetts.

Further reading: *Origins*, Alan Lightman and Roberta Brawer, Harvard University Press, 1990.

World War II's Flying Colors. For Jeffrey Ethell, writing is the price he has to pay to fly the vintage and modern military aircraft featured in his 35 books. He would like to hear from anyone with World War II Kodachromes for his next book. His address is Route 1, Box 315A, Front Royal, VA 22630.

Ha Tovim La Tayis (The Best for Pilots). Samuel M. Katz served in the Israeli Defense Forces and has written 15 books about the Israeli military. His latest, *Israel's Air Force: The Best of the Best*, will be published by Motorbooks in September.

The Smithsonian Traveler

The Latest Word on Study Tours, Seminars and Research Expeditions

Don't miss out! Write for the *Smithsonian Traveler,* a semi-annual newsletter with a complete listing of upcoming programs. More than 180 learning adventures are offered in 1991, including:

Foreign Study Tours
September: Visit battlefields of France and Belgium. Trace European military history from Napoleon to World War II.

Domestic Study Tours and Seminars
September-October: Journey behind the scenes at the Air and Space Museum or study aircraft restoration at the Paul E. Garber Facility. Trace the history of the Manhattan Project at Los Alamos.

Research Expeditions
October/November: Work on a videodisk project in Washington, D.C.

For newsletters and brochures, write Smithsonian Study Tours and Seminars, 1100 Jefferson Dr. S.W., Washington, DC 20560, or call (202) 357-4700.

Calendar

August 2–4
Gathering of Eagles Airshow. Sponsored by Confederate Air Force. Lorain County Regional Airport, Elyria, OH, (216) 323-CAF1.

14th Annual Air Power Display. Sponsored by Confederate Air Force. Holman Field, St. Paul Downtown Airport, MN, (612) 455-6942.

August 3 & 4
Northeast Flight '91 Airshow. Golden Knights, Harrier jump jet, and B-17 *Memphis Belle.* Schenectady County Airport, Schenectady, NY, (518) 382-0041.

August 7–11
Airshow Canada. F-117A stealth fighter. Abbotsford, British Columbia, Canada, (604) 852-4600.

August 17 & 18
Wings of Eagles Airshow. National Warplane Museum, Geneseo, NY, (716) 243-0690.

August 22–25
Sentimental Journey to Cub Haven Fly-In. Under-the-wing camping and corn roasts. William T. Piper Memorial Airport, Lock Haven, PA, (717) 893-4207.

September 7
Tri-State Airline Historical Society's Airline Collectibles Show. Newark Airport Vista Hotel, Elizabeth, NJ, (914) 965-3010.

September 15
Lake Whatcom Splash-In. Sponsored by Seaplane Pilots Association. Bellingham, WA, (206) 463-2460.

September 21
The Santa Fe Air Show. Sponsored by the Santa Fe del Sur Rotary Club. Santa Fe Airport, NM, (505) 473-0000.

September 23–27
U.S. National Aerobatics Championship. Denison, TX, (214) 465-1551.

September 28 & 29
Experimental Aircraft Association East Coast Fly-In. Ultralight demonstrations, sailplanes, and pancake breakfast. New Castle County Airport, Wilmington, DE, (301) 942-3309.

Open Cockpit Weekend. New England Air Museum, Bradley International Airport, Windsor Locks, CT, (203) 623-3305.

"The Satellite Sky" Update/25

These regular updates to "The Satellite Sky" chart will enable readers to keep their charts up to date. Additions can be clipped and affixed to the chart at the appropriate altitude.

New launches

90 to 300 MILES

Cosmos 2149
5-24-91 PL

GRO
4-5-91 KSC

Progress M-8
5-30-91 TT

Resurs F-10
5-21-91 PL

Soyuz TM-12
5-18-91 TT

300 to 630 MILES

Cosmos 2142
4-16-91 PL

NOAA-12
5-14-91 VAFB

Okean 3
6-4-91 PL

DATA: SAUNDERS KRAMER

630 to 1,250 MILES

Cosmos 2143-48
5-16-91 PL

Meteor 3-4
4-24-91 PL

21,750 to 22,370 MILES

Aurora 2
5-29-91 CAC

ASC-2
4-13-91 CAC

Deletions

90 to 300 MILES

Cosmos 2046
down 4-16-91

Cosmos 2103
down 4-3-91

Cosmos 2113
down 6-11-91

Cosmos 2138
down 5-24-91

Progress 33
down 12-19-87

Progress M-7
down 5-7-91

Soyuz TM-11
down 5-26-91

Inoperative but still in orbit

300 to 630 MILES	Cosmos 1861	Cosmos 2034
21,750 to 22,370 MILES	RCA Satcom 5	

Launched but not in orbit

90 to 300 MILES

STS-39 U.S. research	4-28-91	down 5-6-91
STS-40 U.S. research	6-5-91	down 6-14-91

Forecast

In the Wings...

Slim Lewis Slept Here. Airmail pioneers and their airplanes are still remembered in Bellefonte, Pennsylvania. When it became the first stop on the New York-Chicago route, this small Pennsylvania town entered a brief golden age.

Sabres Over Korea. Novelist James Salter recalls life in and out of an F-86 cockpit during the Korean War.

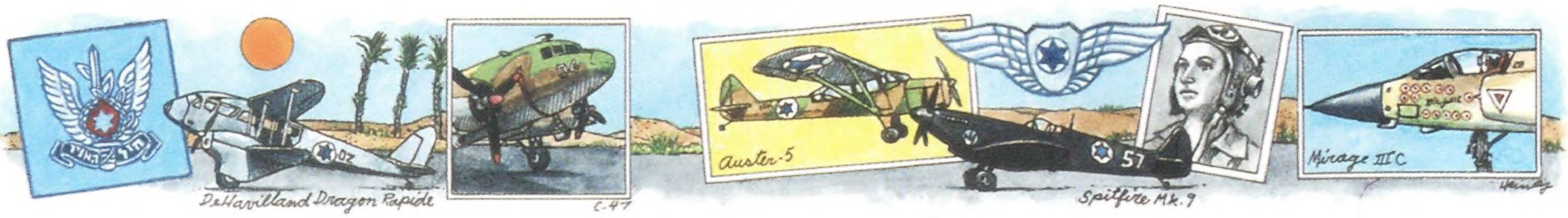
Design for Airports. The entries for a 1930s airport design competition weren't always practical—and sometimes they were downright weird.

Flying World War I Fighters. World War I air combat was a deadly business. And many an aviator discovered that the most dangerous enemy was his own airplane.

Spies in the Skies. Satellites can help one country keep tabs on another, but the information they provide is only as good as the people interpreting it.

Moving Day. Building the airplane was the easy part. Now it's time to get it out of the barn...

Lights, Camera, Data! Using information gathered by space probes, scientists have created some unique motion pictures of voyages around other worlds.



JOHN HEINLY

Ha Tovim La Tayis (The Best for Pilots)

On a desert airstrip, heatwaves shimmer off the fuselage of a Boeing 707. Emblazoned on the airliner's wings is a blue Star of David. The passengers waiting to board the 707 will soon find themselves in the thick of a chase as Israeli F-4E Phantoms pursue enemy MiG-21s. The aerial combat won't take place outside their windows, however, but on a large movie screen inside the airliner cabin.

This ground-bound airplane is one of the exhibits at the Israeli Air Force Museum. Until only recently the IAF had been preoccupied with the threat of Scud missiles; indeed, the Gulf war delayed the museum's official opening until last July. Eventually, that conflict too will be represented at the museum.

Located in the Negev Desert near Beersheva, the museum is adjacent to the Hatzerim Air Base. After seeing the museum's historic aircraft, visitors can watch modern aircraft departing from the nation's major military flight training facility.

At the museum's entrance, soldiers stand guard with assault rifles—a reminder that Israel is always on alert. The museum's main facility, Heritage Hall, offers welcome relief from the scorching desert temperatures. Three wings cover nearly half a century of Israeli air power, including exhibits on the 1976 rescue of hostages in Entebbe and the 1981 bombing of Iraq's Osirak nuclear reactor. Other exhibits feature an impressive array of weapons systems, a three-dimensional scale model of an aerial battle, and a computer-generated illustration of a Mach 2 dogfight from the pilot's perspective.

Written narratives, both Hebrew and English, accompany the displays, and khaki-uniformed female guides are available to answer questions. Most of the guides are completing their two years of compulsory military service, and they are extremely well versed in Israel's military history; for instance, they can recount for visitors each kill represented by the 13 red, black, and white roundels below the windscreen of a Dassault-Breguet Mirage IIIC fighter.

Some information, however, remains classified. "Even relics such as Mirage IIICs and Vautours have their secrets," says Sergeant Limor (her last name could not be released for security reasons). "We have to be even more careful when talking about the Kfir fighter-bombers which are here. They participated in many air battles over Lebanon, the details of which are not yet public record."

The force behind the museum is Yacov Terner, a former fighter pilot and Hatzerim base commander who serves as the museum's director. The retired brigadier general—also Israel's police commissioner—proudly displays his pilot wings on his police uniform. To get the museum off the ground, Terner had to blaze a trail through Israel's elaborate bureaucracy. Only slightly less challenging was convincing former IAF pilots to contribute memorabilia—uniforms, insignia, and other souvenirs—to the collection.

The museum's original purpose was to exhibit an example of each aircraft the Heyl Ha Avir (Israeli Air Force) has flown since Israel declared independence in 1948. That year, the infant nation had to fend off five neighboring states, and at one point resorted to deploying British Auster Mk.5s to bomb the advancing enemy with empty seltzer bottles. It wasn't until the first shipments of Avia S.199 fighters (Czechoslovakian copies of the Me-109G) arrived later that year that Israel's new air force was able to defend its skies.

Over the years the aircraft that initially bestowed grandeur and prestige on the IAF became obsolete. Eventually Terner decided he would gather neglected airplanes displayed in schoolyards and tucked away in remote corners of air force bases. Now 95 aircraft are exhibited at the museum, and each has a story to tell: a silver-gray de Havilland Dragon Rapide biplane that flew emergency bombing runs during the War of Independence, a camouflaged North American P-51 Mustang used to sever Egyptian telephone lines with its propeller in the opening hours of the 1956 war, a Sud Aviation S0-4050 Vautour IIA that attacked Iraqi airfields during the Six Day War of 1967.

Also on display are some aircraft that never served with the IAF—a Syrian Air Force Aerospatiale SA342L Gazelle helicopter gunship captured in Lebanon, a Syrian MiG-17 delivered by a pilot who mistook Haifa for Beirut, and an Iraqi MiG-21 brought to Israel in 1966 by the Mossad, the nation's foreign espionage service.

The vintage aircraft are the museum's main attraction, and visitors are permitted to touch struts, wheels, and tires. Many of the historic aircraft parked on the sun-baked tarmac are intricately camouflaged to blend in with the rugged Mideast terrain. Near a camouflaged C-47 Dakota that in 1956 dropped paratroopers into the Mitla Pass gauntlet is a sleek black Supermarine Spitfire Mk.9, maintained in perfect flying condition. Some 15 airworthy aircraft are allowed to fly periodically in museum-sponsored activities and air force exhibitions, and often it's the museum director, Terner himself, who will be found in the cockpit.

The aircraft of the IAF have captured Israel's affection, and the air force's old motto, "*Ha Tovim La Tayis* (The Best for Pilots)," still echoes inside the museum. Former pilots are especially swept up by the collection. The museum is also popular with youngsters. During a recent field trip, 12-year-old Eran dashed madly from one aircraft to another. "This is a C-47," he shouted to his classmates. "This is a Meteor, this is a Mystére, and this is the famous Iraqi MiG-21." Like many youngsters who visit the museum, Eran dreams of someday returning—perhaps next time to attend the IAF's flight school.

—Samuel M. Katz

Israeli Air Force Museum, Military P.O. Box 02832, IDF (Zahal), Israel. Telephone (972) 057-906428. To arrange visits, contact the museum.

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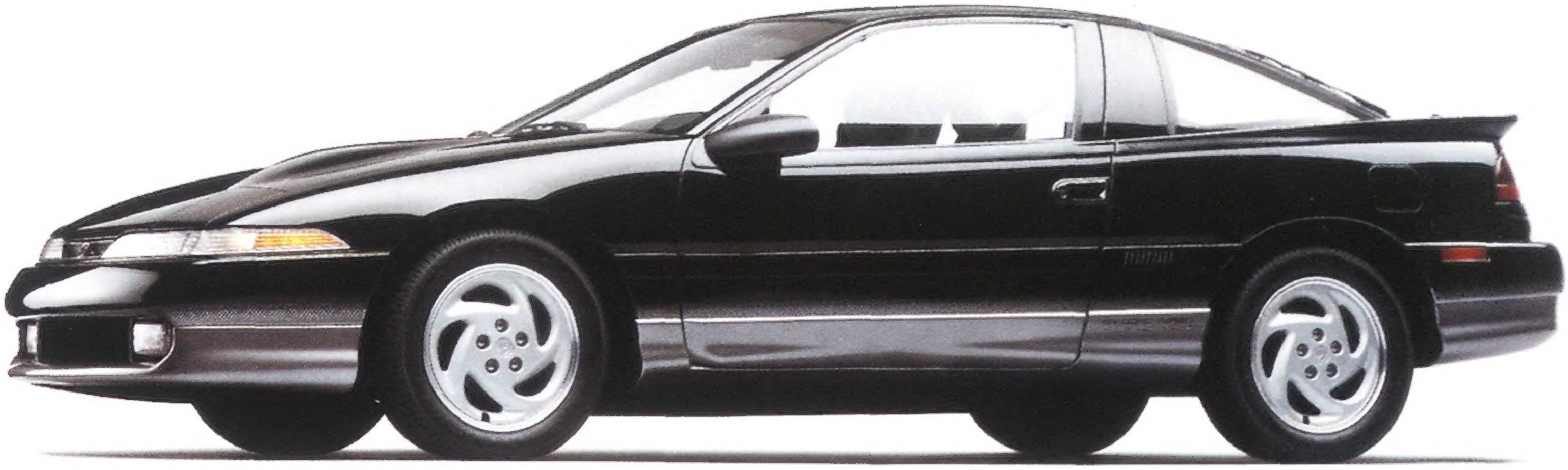

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